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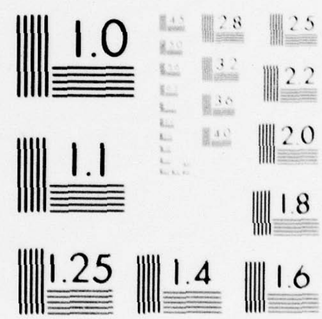

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Four chapters discuss the distribution of the remains of micro-organisms in the surface sediments of the Pacific Ocean. Species composition and quantitative distribution are described. Biogeographic regions and taxo coenoses are defined. Data were derived from 1949-1961 cruises of the VITYAZ' and 1956-1958 voyages of the OB'.

THE ACADEMY OF SCIENCES OF THE USSR

P. P. SHIRSHOV INSTITUTE OF OCEANOLOGY

THE PACIFIC OCEAN

Volume VIII

Microflora and Microfauna in Recent Sediments of the Pacific Ocean

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Publishing House "NAUKA"

Moscow 1969

PREFACE

5/ This book presents results of research into the composition and distribution patterns of diatoms, silicoflagellates, radiolarians, and planktonic and benthic foraminifera in Recent sediments of the Pacific Ocean. Data for these studies were numerous samples of the surface sediment layer collected during the 1949-1961 VITYAZ' expeditions of the USSR Academy of Sciences, Institute of Oceanology, and the Soviet Antarctic expeditions of the R. V. OB' in 1956-68. In addition, published data from expeditions by other countries were used.

Diatoms, and planktonic and benthic foraminifera were studied in Recent sediments of the North and South Pacific Ocean, but radiolaria were studied only in the North Pacific.

Each chapter contains new data on the quantitative distribution and species composition of microorganism remains (skeletons or tests) in Recent sediments. Special attention was devoted to biogeographic regionalization of the Pacific Ocean based on the distribution of microflora and microfauna. Typical complexes of diatom, radiolarian, and planktonic foraminiferal species have been defined for different ocean zones. Different taxocoenoses have been distinguished, based on quantitative determinations and species composition of benthic foraminifera. Latitudinal and vertical zoning have been detected in their distribution.

It has been determined that the distribution of diatoms, silicoflagellates, radiolarians, and planktonic foraminifera in the surface sediment layer reflects their characteristic contemporary distribution in Pacific Ocean waters. Their distribution in the Pacific Ocean sedimentary series as a whole generally differs considerably from the contemporary one. Consequently, rational use of all micropaleontologic methods to deduce the geological history of the ocean must rest on data showing their contemporary distribution. Pertinent chapters of the present volume as well as of volume VI describe the role of diatoms, radiolarians, and foraminifera in deposits of siliceous and carbonaceous organogenic sediments in the ocean.

Data obtained on the surface sediment layer distribution of diatoms, silicoflagellates, radiolarians, and planktonic and benthic foraminifera can be used to determine the stratigraphy of sediments and paleogeography not only of the Pacific Ocean, but also of the World Ocean.

Chapter I - Diatoms and Silicoflagellates in the Surface Sediment Layer of the Pacific Ocean - was written by A. P. Zhuze together with V. V. Mukhina and O. G. Kozlova; Chapter II - Radiolaria in the Surface Sediment Layer of the Northern Basin of the Pacific Ocean was written by S. B. Kruglikova; Chapter III - Planktonic Foraminifera in the Surface Sediment layer of the Pacific Ocean was written by N. V. Belyayeva; Chapter IV - Distribution and Ecology of Recent Benthic Foraminifera in the Pacific Ocean - was written by Kh. M. Saidova.

The work was done in the Marine Geology Section of the USSR Academy of Science P. P. Shirshov Institute of Oceanology. I. O. Murdmaa edited this volume. G. N. Nedesheva and Z. P. Bundina processed the data on foraminifera, while I. K. Vasil'yeva and Ye. I. Pochechuyeva prepared the figures.

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Publication, The Pacific Oceans, prepared by the scientific staff of the Shirshov Institute of Oceanology, USSR Academy of Sciences, consists of the following volumes: I-Meteorological Conditions over the Pacific Ocean, II-Hydrology of the Pacific Ocean, III-Chemistry of the Pacific Ocean, IV-Shores of the Pacific Ocean, V-Bottom geomorphology and tectonics of the Pacific Ocean, VI-Sedimentation in the Pacific Ocean (Books 1 and 2), VII-Biology of the Pacific Ocean (Books 1, 2 and 3), VIII-Microflora and Microfauna in the Recent Sediments of the Pacific.

The book, Microflora and Microfauna in the Recent Sediments of the Pacific, contains a review of data on microflora (diatoms-silicoflagellates) and microfauna (planktonic and benthonic foraminifers and radiolarias) of the Pacific Ocean based on original data as well as on published results.

Editor-in-chief

Publication "Microflora and Microfauna in Recent Sediments of the Pacific"

Corresponding member of the USSR Academy of Sciences

P. L. BEZRUKOV

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Chapter I

Diatoms and Silicoflagellates in the Surface Sediment Layer of the Pacific Ocean

A. P. Zhuze, V. V. Mukhina, O. G. Kozlova

INTRODUCTION

The surface sediment layer reflects the contemporary distribution of diatoms and silicoflagellates in the ocean. In order to interpret correctly the results of analysis of diatoms in the layer one must, first of all, know the contemporary quantitative content of diatoms and silicoflagellates, as well as their biogeography. Having these data, microfloral analysis becomes a valuable source of information to establish the geologic history of the ocean and its sedimentation conditions. The Pacific Ocean is one place where the diatom analysis method can be used successfully. Among biological and geological forms of the ocean, diatoms are the main source of deposits of organic matter, the first link in long food chains. In temperate latitudes of the northern part of the ocean, as well as in Antarctic regions, 90-95% of phytoplankton consist of diatoms which, together with silicoflagellates, settle to the bottom and form part of the sediment deposits. The deposition process is practically continuous. In some regions mass accumulation of diatom remnants occurs, while in others, accumulations are noticeably smaller.

Up to now, the typical features of diatom and silicoflagellate distribution in the Pacific Ocean surface sediment layer have remained largely unknown. Even though their distribution on the bottom reflects mainly their distribution in the active layer (water) of the ocean, significant deviations, mainly of the quantitative type, depend on a number of factors: dilution by terrigeneous material, different species rates of decomposition, etc. Actually there are no cases of complete coincidence among diatoms in biocoenoses and thanatocoenoses, because population size and species composition of diatoms change constantly. Very large quantities of these organisms are dissolved in the 0 - 300 m layer immediately after vegetation ends. At the present time, it is known that there are more species that rapidly, partially or completely decompose among neritic diatoms than among oceanic (diatoms). Distinct species complexes, among which diatoms with a slow decomposition rate predominate, are formed in the sediments. Quite often these species do not attain mass development in the plankton. Cases where the mass species of plankton are also the same (mass species) in sediments are very rare.

Of course, diatom complexes in sediments contain only species that can be found in plankton (excluding quite frequent cases of redeposition). However, in bottom sediments, their species composition acquires new aspects due to the different decomposition rate in the fossil (sediment) state. From this it follows that diatom analysis is an independent scientific field, which has problems different from those found in studies of diatom biology.

Silicoflagellates in surface sediments of the Pacific Ocean also were studied. Their distribution and species composition in the Pacific
8/ Ocean were previously unknown. Although the content of these organisms in deposits of organic silica in sediments is considerably lower than that of

diatoms, it can not be disregarded. Silicoflagellates inhabiting surface water descend almost unchanged to the bottom, because their siliceous skeletons are very durable. It seems that they also are insoluble in the stomachs of zooplankton organisms. Most silicoflagellate species are concentrated in lower latitude sediments, which points to their natural preference for warm water. They are good indicators of water masses and in this respect, with diatoms, supplement each other. Ecologically similar and mutually associated complexes of diatoms and silicoflagellates can be seen in the surface sediment layer.

History of Research

The beginning of study of diatoms in recent sediments of the oceans for geological purposes was begun by Lohman (1942) and Kolbe (1954). The former studied diatoms in North Atlantic Ocean bottom sediments, the latter - in sediments of the Pacific equatorial zone and, later, in the Indian and Atlantic Oceans. Previous scientific work dealing with diatoms in oceanic sediments had different aims. Only the appearance of Lohman's, and then Kolbe's works, redirected the study of diatoms to their use in marine geology.

In the Soviet Union, the first scientific work on diatoms in bottom sediments of the Okhotsk and Bering Seas appeared in 1954 (Zhuze, 1954a, b). At the present time, scientific work on diatom analysis of Pacific Ocean bottom sediments is concentrated mainly at the Institute of Oceanology of the USSR Academy of Sciences. On a much smaller scale, this work is also carried on in the USA, at Scripps Institution of Oceanography and Lamont Observatory of Columbia University, as well as in Japan. For a period of several years, T. Kanaya (1961) devoted himself to the study of diatoms in bottom sediments of the eastern part of the ocean.

During the first years workers at the Institute of Oceanology USSR Academy of Science devoted their principal attention to perfecting different methods of diatom analysis and had primary roles in the development of this method (Zhuze, Semina, 1955). Studies of the taxonomic composition of diatoms and of peculiarities of their distribution in sediments were conducted simultaneously (Zhuze, 1957, 1959b; Belyayeva, 1961; Zhuze, Sechkina, 1955). As a result, a rich accumulation of data made it possible to determine the distributional features of diatoms in sediments of the Okhotsk, Japan, and Bering Seas. This initial stage improved knowledge of the characteristics of diatom distribution in Pacific Ocean sediments.

Data on suspended matter was used to determine the mechanism of diatom deposition in sediments. The organogenic part of suspended matter consists of a greater or lesser quantity of diatom valves and tests (shells or skeletal remains) with average dimensions of approximately 0.05 mm. O. G. Kozlova's (1964) studies of suspended matter collected along three meridional sections, from the ocean surface through the entire water column, contributed to much better understanding of the formation of diatom complexes in sediments. Data on the difference between decomposition rates of neritic and oceanic species of diatoms were specifically verified.

The composition and distribution of diatoms in the surface sediment layer of the Pacific Ocean from its northern boundary to 48°S was studied by T. V. Belyayeva (1963). The data collected by the R. V. VITYAZ' were supplemented by samples from the Southeast Pacific Ocean obtained from W. Riedel, a member of Scripps Institution of Oceanography. A total of 463 samples were studied. T. V. Belyayeva distinguishes two diatom species

complexes: boreal and tropical, not counting the Antarctic complex which appears in sediments at the southern boundary of the region under study. The deficiency of T. V. Belyayeva's charts (maps) of diatom distribution in sediments is the underestimation of quantitative data on the distribution of species within their distribution range. As a result, one has a false impression of the homogeneity of the quantitative distribution of species within a large distribution range.

The quantitative aspect, which is extremely important in determination of the principal biogeographic boundaries or distribution range centers of any one species, because of this treatment remained unexplained.

Among foreign scientific works, the most important study is Kolbe's (1954) monograph. It is based on the results of studies of diatoms in sediments of the Pacific Ocean equatorial zone obtained by the Swedish deep-water expedition on the ALBATROSS in 1947-48. One of the best specialists on marine diatoms, Kolbe, has greatly improved the method of diatom study. His is the concept of thanatocoenoses of diatoms in bottom sediments. Most of Kolbe's work was devoted to classification of species in the equatorial zone. In addition, he traced changes in diatom composition through a series of several sediment cores, these data later were interpreted geologically in works of Arrhenius (1952, 1960).

T. Kanaya (1961) made a study of diatoms in the surface sediment layer of the eastern Bering Sea and of the eastern regions of the Pacific Ocean. Kanaya distinguishes four diatom complexes in sediments of these regions. He thinks that these (complexes) originated from biocoenoses of algae that inhabit subarctic, temperate (boreal), tropical (equatorial), and subtropical water masses. The results of Kanaya's studies have been reduced to a table in Bramlette's (1961) work. In this table, typical species compositions are listed in latitudinal sequence, from the Bering Sea to the Antarctic.

Large numbers of scientific works have been devoted to the special question of the genesis of *Ethmodiscus* oozes. It seems that they were first mentioned by Flint (1905), who studied bottom sediments in the Marianas Islands region. Later on, Mann (1907) studied samples of *Ethmodiscus* oozes collected in the same region by the American ALBATROSS expedition in 1888-1904. The Japanese lithologist, Hanzawa (1933), delineated areas of deposition of *Ethmodiscus rex* Wallich in sediments between the islands of Guam and Luzon. Riedel (1954) was inclined to assign Tertiary age to the *Ethmodiscus* ooze samples obtained in the Marianas Trench by the 1872-1873 CHALLENGER expedition. Wiseman and Hendey (1953) made the first attempt to summarize all available data on occurrences of *Ethmodiscus* oozes in plankton and in Pacific Ocean sediments. However, these investigators came to no definite conclusions about the genesis of these oozes, the main problem, to which they found no answer, was how did thick layers of *Ethmodiscus* oozes accumulate if this species rarely occurs in plankton. And, the question of their Tertiary age cropped up again.

Kolbe (1954, 1955, 1957) also mentioned *Ethmodiscus* oozes in his monographs. He thought these sediments are typical of tropical regions of the World Ocean. Kolbe also expressed opinions that are close to modern concepts on the genesis of this type of diatomaceous sediments and emphasized the significance of the exceptionally large size of *Ethmodiscus rex* Wallich and its resistance to dissolution processes.

10/ Samples of Ethmodiscus oozes were obtained in the Yap and Marianas trenches during geologic studies of the Western Pacific Ocean by the VITYAZ' expedition. According to A. P. Zhuze, V. P. Petelina, and G. B. Udintseva (1958), the problem of the origin of this type of sediment can be understood if one considers the very large size of the Ethmodiscus shell (it is 1,000 times larger than that of the common tropical species Coscinodiscus nodulifer) and its slow decomposition rate in sediments. The irregularity of the distribution of Ethmodiscus ooze on the Pacific Ocean floor is caused by submarine relief features, which play a deciding role in this process. Ethmodiscus oozes are formed mainly in bottom depressions where they appear as gelatinous masses. Light Ethmodiscus fragments slide in suspension down elevated relief features and accumulate at their bases.

As can be seen, a large amount of data, which reveals the different aspects of diatom distribution in surface sediments of the Pacific Ocean, has been accumulated in Soviet and foreign literature.

Materials and Research Methods

Surface sediment layer samples obtained during expeditions of the ships VITYAZ' and OB' formed the initial materials. Samples from 200 stations (fig. 1) were examined to determine the quantitative distribution of diatoms and their species composition. Most of these were bottom dredge samples, while some were the surface layers of cores. One method used was to examine diatoms in unseparated dry sediments. Practice has shown that, in specimen samples taken only from the silt fractions of sediments, the quantity of valves similar in size to these fractions, i.e., of valves 50-100 and 50-10 microns in diameter, was artificially increased. The greatest quantity of diatoms appears in the fine silt fraction. The significant deficiency of specimen samples taken from separated and washed sediments is the absence of the fraction less than 0.01 mm. The latter fraction often contains small valves (those smaller than 10 microns) and their fragments. When taking specimen samples it is wise not to disregard the pelitic fraction, even though it muddies up the diatom valves and causes difficulties in classifying, counting, and photographing them. In specimen samples taken from unseparated sediments, diatoms are found in ratios most closely resembling those found in nature. However, because using such a method of microscope specimen preparation does not achieve high concentration, some rare species can be lost. Comparison of specimen samples from the fine silt fraction of sediments with specimen samples from unseparated sediments has shown that the latter samples sometimes lack certain rare or single specimen species. In individual cases, studies of two types of samples are recommended: concentrated samples and, paralleling these, natural sediment samples.

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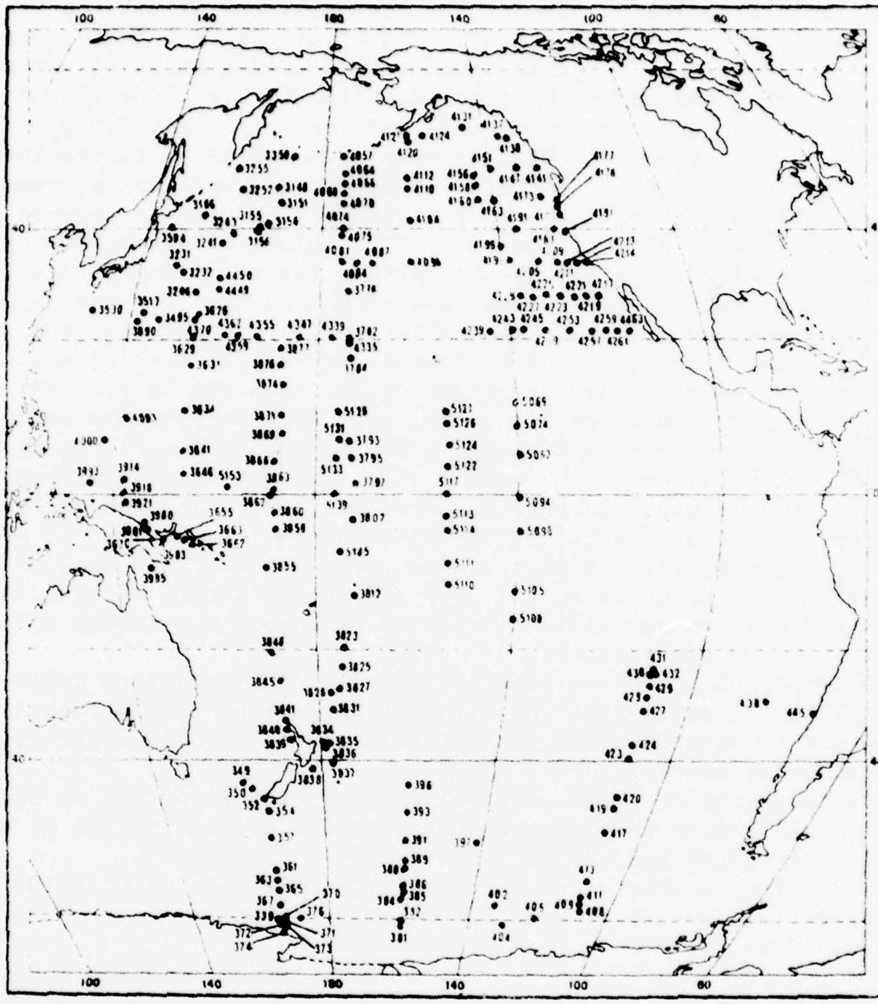

Fig. 1. Chart of stations at which diatoms were studied in the bottom sediments (from material collected by R. V. VITYAZ' and OB').

10/ Method of preparation of a sample specimen from unseparated dry sediment

Natural sediment in the amount of 0.5 g was placed in a 100-ml heat resistant glass beaker, covered for 3-5 hours with twenty-molar solution of potassium tripolyphosphate ($Na_5P_3O_{10}$)[1] and boiled for 15 minutes (without being completely dehydrated). The sediment was (dispersed) in the tripolyphosphate. The sediment was boiled in the same vessel while 30% Perhydrol (20-25 ml in all) was added gradually. Perhydrol facilitates the separation of diatom valves from various organic admixtures. The potassium tripolyphosphate and Perhydrol are separated from the purified sediment in

[1] The sediment must be completely covered by the tripolyphosphate solution.

11/ distilled water using a centrifuge. The degree of purity is checked by
standard RN-1-10 indicator paper. The pure sediment is diluted by distilled
water so that the diatom concentration in it will permit the values to be
counted. The degree of dilution depends on diatom content of the sediments.
For Pacific Ocean sediments the usual dilution is 0.5 g per 100 ml of water.
When the diatom content in diatom ooze sediments is high, 0.5 g must be
diluted by 200 ml of water. Diatomaceous oozes of Antarctic regions usually
are diluted with 200-400 ml of water or more. The sediment suspension is
very thoroughly mixed and 0.08 ml of constantly and evenly stirred suspension
is placed on a cover glass (scoured). This volume of suspension corresponds
to 0.4 mg of sediment. After natural drying (at room temperature), the
sample is coated with resin by the same method as used for the separated and
concentrated sediments. It is desirable that in each sample, the diatoms be
12/ counted at equal intervals in 8 horizontal rows. The species are classified
simultaneously. The average number of diatoms counted in each row is
multiplied by 120 (number of horizontal rows in a sample when studied under
a X90 immersion lens) or by 80 (when a X60 immersion lens is used). The
number of diatom valves in one sample, i.e., in 0.4 mg of sediment, is
determined in this way. Subsequent recalculations yield the number of
valves per gram of sediment. Valves of each species are counted at the same
time in the sample; their number can be shown on charts in absolute numbers
or in percent of the total quantity of all the different species in the
sample. Radiolarian and silicoflagellate skeletons and sponge spicules can
be counted in the same samples.

The method of preparing specimen samples from undivided sediment makes it possible to determine the quantitative content of all siliceous organic remnants and to determine the content values most closely representing the natural sediment composition.

Recalculations to obtain the quantity of diatoms per 1g of sediment were made in the following way: <u>for example</u>, if the average number of diatom valves in one row of the sample is 37:

1) 37 X 120 (number of rows in an 18/18 mm sample using a X90 lens) = 4,440 valves in one sample or in 0.4 mg of sediment;

2) 4,440 valves - 0.4 mg;
X valves - 1 g;

$$X = \frac{4,440.1}{0.4} = 11,100,000 \text{ diatom valves in 1 g of sediment.}$$

Undamaged valves and large valve fragments are counted and totaled in the calculations. Diatom detritus and fragments smaller than 5 microns cannot be evaluated quantitatively. The number of fragments of such large diatoms as <u>Thalassiothrix</u> or <u>Ethmodiscus</u> had to be divided by 10 for <u>Thalassiothrix</u> and by 50 for <u>Ethmodiscus</u>.

It should be added, that the sediment samples studied in the Pacific Ocean were extracted at 5-10 cm intervals along the core. Experience has shown that a less densely spaced sample often leads to incorrect biostratigraphic determinations. In selecting samples to study diatoms, one must also consider the lithologic composition of the sediments.

Results of the diatom analysis can be depicted on charts to show the distribution of some species in the ocean, or in graphs (tables) to summarize data on the distribution of species in the sediment layer. In these cases the quantitative content of each species is given in percent of the total number of valves or in absolute numbers of valves per 1 g of sediment.

Quantitative Distribution of Diatoms

in the Surface Sediment Layer

Data from more than 200 stations make it possible to form a reasonably accurate idea of the quantitative distribution of diatoms in the surface sediment layer over a considerable area of the Pacific Ocean floor. In the northern part of the ocean, quantitative determinations have been made in greater detail than in the southern and, especially, in the southeastern parts.

The distribution of diatoms in the surface sediment layer of the Bering and Okhotsk Seas also is presented here. In the Bering Sea, analogous data,
13/ i.e., data for one gram of dry sediment, was obtained at only 20 stations. In the Sea of Okhotsk, diatom content was determined in the fine-silt fraction of the sediments (Zhuze, 1957). Consequently, during the delineation of isolines in the Okhotsk and Bering Seas we were forced to rely on data on the content of amorphous SiO_2 in the sediments (Bezrukov, 1955; Lisitsyn, 1955). Until now, data on the quantity of diatoms in the surface sediment layer of the Pacific Ocean was practically nonexistent. Kolbe's (1954) calculations applied only to valves of one tropical species-Coscinodiscus nodulifer A. S., and the author was interested in the character of quantitative changes in the sediment layer for the purpose of its stratigraphic division. A. P. Zhuze (1963) and V. V. Mukhina (1963) determined the quantity of diatoms in core samples for the same purpose. General data on the quantitative distribution of diatoms in the surface sediment layer, from the northern boundaries of the ocean to 40°S., was presented by T. V. Belyayeva (1961). She evaluated the diatom content of sediments relative to a scale based on the quantity of diatoms in the fine-silt fraction of the sediment, i.e., as "en masse," "frequently," "rarely," and "individually" found.

Consequently, the chart of quantitative distribution of diatoms (fig. 2), based on a direct count of valves in 1g of sediments, characterizes the diatom content of surface sediment layer with greatest precision.

The quantitative distribution of diatoms on the bottom is a clear reflection of their distribution in the active (water) layer of the ocean. The principal areas of especially dense diatom plankton population correspond to sediments of the diatom ooze type. There is, however, no complete correlation between these large areas of foraminiferal habitat in water and the distribution of the foraminiferal remains in sediments, because in the most productive regions of the ocean, which usually are close to the coasts; terrigenous material dilutes the concentration of diatoms in the sediments. However, under conditions of insignificant terrigenous dilution, diatom oozes can form even on continental shelves (on the northern shelves of the Sea of Okhotsk and near the shores of Antarctica, for example). The discrepancy between the quantity of diatoms in surface waters and in sediments, also is related to the dissolution of the valves of these diatoms during their descent to the bottom.

Diatoms inhabiting coastal waters (so-called neritic species) have a high decomposition rate compared with open ocean species. According to O. G. Kozlova's (1964) data, not more than 5-7% of the initial quantity of cells of Antarctic neritic diatomaceous plankton reach the bottom. In regions far from the coast, the picture changes significantly. In the first place, terrigenous dilution is insignificant there, and, secondly, the decomposition rate of oceanic species is several times slower than (that of) neritic (species).

The dependence of the quantitative distribution of diatoms on the Pacific Ocean bottom on climatic zones can be seen, and is similar to that observed in the distribution of all other planktonic organisms. Mass accumulations of diatoms in sediments in the northern oceans are confined to divergence zones with intensive horizontal and vertical intermixing of waters, which causes enrichment of the surface waters with biogenic elements. Similar factors control the accumulation of siliceous sediments in the pre-Antarctic regions of the Pacific Ocean.

The variation in diatom quantity in sediments is quite large; it ranges from almost complete absence to maximum concentrations, where diatom valves comprise from 50 to 70% and, possibly even more, of the total sediment. Data permit identification of six gradations of diatom content in the surface sediment layer of the Pacific Ocean: (1) from more than 100 million to a maximum of 440 million valves/g of sediment; (2) 100-50 million valves/g; (3) 50-25 million valves/g; (4) 25-5 million valves/g; (5) less than 5 million valves/g, and (6) diatoms are practically absent.

14/ As seen from the chart (fig. 2), the highest concentrations of diatoms are found in the southern part of the ocean in pre-Antarctic regions. These concentrations are correlated with the diatom ooze distribution zone. Specifically, we counted 227, 314, 378, 412, and 441.6 million valves/g of sediments there. The southern boundary of diatom sediments approximately follows 65°S., coinciding in several regions with the Antarctic divergence zone. The northern boundary of diatom sediments lies in places behind the Antarctic convergence zone, particularly at stations along 160°W. Data on the quantity of diatoms at station 419 (47°S., 110°W.), where there were almost 80 million valves/g, were a surprise. The influence of upwelling
15/ water in this area was reflected in the profuse development of flowering diatoms in the plankton (Naumov, Zernova et al., 1962). The Bering Sea is also a zone of very rich siliceous deposits.

Approximately 100 million valves/g have been counted at a series of stations in the eastern and western deep-water basins of the Bering Sea. For example, the content of Coscinodiscus marginatus Ehr. is close to 1 million valves/g (Zhuze, 1959a). This is one of the mass species of diatoms with very large, coarse, siliceous structure, which predominate in the open regions of the Okhotsk and Bering Seas and adjacent parts of the Pacific Ocean. Its role, certainly, is one of the most important in the accumulation of biogenic silica in sediments of the aforementioned regions. The concentration of diatoms in diatom oozes of the Sea of Okhotsk is approximately the same as in the Bering Sea.

The quantity of diatoms in sediments of the North Pacific Ocean is somewhat lower. At most stations, it was less than 50 million valves/g. The sediments at stations 3155 and 3156 are somewhat richer (in diatoms), but even there the quantity of diatoms does not exceed 55 million valves/g. From the northern boundaries of the Pacific to approximately 35°N in the west and 50°N at the coast of North America, sediments contained from 50 to 5 million valves/g. A large region of diatom sediments is located along the Kurile and northern Japanese islands. It forms a wide strip between 45° and 35°N, extending latitudinally almost to 175°W. The strips of diatom ooze end in the region of Emperor Seamount Chain, which is covered with carbonaceous sediments. At station 3148 located in these seamounts, the diatom content drops to 1.9 million valves/g, i.e., it is approximately 8 times lower than at nearby stations.

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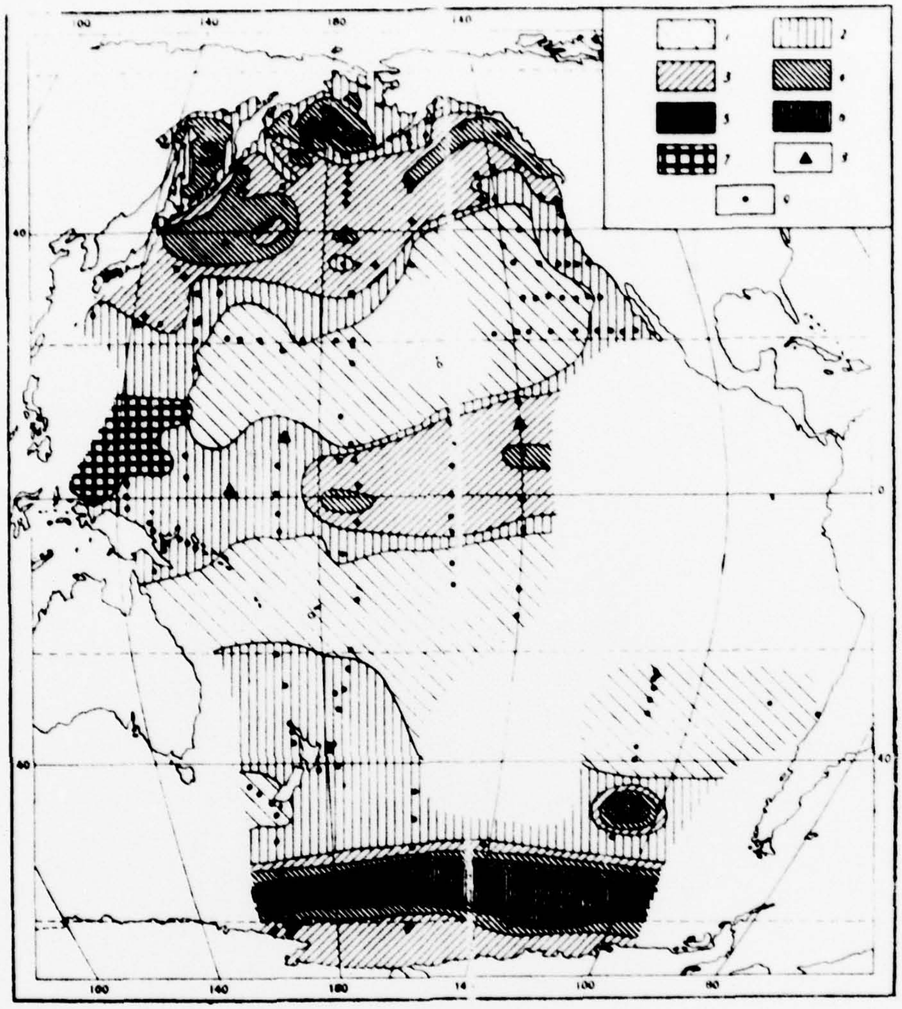

Fig. 2. Quantitative distribution of diatoms in the surface sediment layer (million valves/g of sediment).

1. diatoms not found; 2. 0.04-5.0; 3. 5-25; 4. 25-50; 5. 50-100; 6. >100; 7. region of distribution of Ethmodiscus ooze; 8. Zone of outcrops of tertiary sediments; 9. stations studied.

15/ Similar concentrations of diatoms are seen in sediments near the coast of North America, in the Gulf of Alaska, and farther south to approximately 48°N, where more than 25 million valves/g were counted at 5 stations. The maximum quantity, 38.5 million valves/g, occurred at station 4138. Typical diatom oozes are formed in the Gulf of California.

South of 35°-40°N, over an extensive bottom area, the quantity of diatoms in sediments does not exceed 25 million valves/g and usually does not exceed 15-13 million valves/g; at station 3778 (30°N, 175°W) there were only 9.3 million valves/g. This is the southernmost station at which diatoms still have a low rate of decomposition, although many thin-walled valves show obvious effects of corrosion. In the western part of the ocean at the same latitude, the decomposition rate of diatoms is slightly less. East of 145°W, a sharp decrease in diatom remnants in the sediments is seen, and the quantity of diatoms at all stations was less than 5 million valves/g. Consequently, one sees a certain asymmetry in the quantitative distribution of diatoms in sediments of the northeastern and northwestern borders of the ocean, and the zone of terrigenous sediments is wider off the coast of North America than near Japan. The lowest group, delineated by the 5 million valves/g isoline on the chart, is typical of terrigenous sediments of the shelf of the Bering Sea and North America. At a series of stations there, no diatoms were found in the sediments.

South of 20°N in the western ocean, and between 30°-42°N in the east, is an extensive region of sediments without diatoms. This region extends to 45°N and ends in the equatorial zone at a strip of diatom-radiolarian oozes with a maximum diatom content of 35.4 million and a minimum of 11.23 million valves/g of sediment. In the central part of the ocean, east of 180°W, a
16/ zone of sediments, especially rich in diatoms, lies between 6°N and 5°S. In the eastern part of the ocean it widens perceptibly to the north and reaches 14°5'N along 140°W. Consequently, the equatorial zone of diatom sediments is uneven in width. Shallow water sediments along the Peru coast (to 30°S) are also relatively rich in diatoms. An interesting peculiarity of diatoms in equatorial latitudes was their low decomposition rate and relatively high concentration in carbonate oozes. After such oozes were treated with hydrochloric acid, the diatoms emerged in very large numbers.

The following detail attracts attention. In the diatom rich zone, at station 5074 (10°N, 140°W) the quantity of diatoms dropped suddenly to 1.86 million valves/g. Analysis of diatoms in sediments of this station exposed their Tertiary age. This fact explains the deviation in quantity of diatoms. Tertiary deposits also have been observed at station 5153, which will be discussed below.

In the Hawaiian Islands region, the quantity of diatoms in sediments was calculated for 11 stations. At most of them, it is less than 0.6 million valves/g. Similar picture is seen in sediments around New Zealand.

Ethmodiscus oozes are confined to tropical parts of the ocean. They were found on the bottom of the Philippine, West Marianas, and East Marianas trenches in cores at stations 4000, 4003, 3678, 3709, 3725, 3727, and 3728. The consistency of *Ethmodiscus* oozes is almost liquid; in their outward appearance they resemble liquid (amorphous) glass. It is practically impossible to determine the number of *Ethmodiscus rex* valves per gram of dry sediment, because this species appears in sediments only as fragments and nobody knows how many of these should be assigned to a single shell of these giants among the diatom species. It is known that the volume of *Ethmodiscus rex* tests is 1,000 times greater than the common tropical species *Coscinodiscus nodulifer* A. S. The region of *Ethmodiscus* ooze distribution is delineated on the chart (fig. 2).

Such are the principal features of the quantitative distribution of diatoms in the sediment layer of the Pacific Ocean. Based on comparison of bottom deposits, the following conclusions can be drawn:

Diatom oozes of the Antarctic region yield the highest quantitative indices, which, in all cases, are greater than 100 million valves/g.

The diatom content of Okhotsk and Bering sea diatom oozes is lower. In addition, rather sharp fluctuations of diatom content occur at neighboring stations; (this content) sometimes drops to 14 million valves/g in these regions.

In diatom oozes of the North Pacific Ocean, the diatom content reaches a maximum of 55 million valves/g, but in sediments transitional to red clays with a 5-10% content of amorphous SiO_2, it is approximately 1.5-2 times smaller. In terrigenous sediments of the northwestern and northeastern borders of the ocean, diatom content does not exceed 5 million valves/g. The same values are typical of ice-rafted sediments off the coasts of Antarctica.

Deep-water red clays, distributed extensively on the bottom in tropical latitudes of the Pacific Ocean, as a rule, do not contain diatoms. In some samples, individual badly decomposed valves are found. The lack of diatoms in red clays is due, primarily, to the extreme scarcity of diatoms in plankton of the tropical region of the ocean and the dissolution of tests after they become part of the sediments. In deep-water red clay areas are found rounded, semi-decomposed valves of Tertiary diatoms; they are distinguished by greater silicification and thicker shells. Typically, in sediments transitional to red clay, the dissolution process has not completely affected all diatoms. The best silicified valves are selectively well preserved, while
17/ others bear traces of corrosion: the shell walls become thinner, the structure loses its clarity and gradually becomes indistinguishable. Below 15-20 cm from the surface of the bottom, diatoms often completely disappear in the surface sediments.

In strongly carbonaceous sediments and in coccolith-foraminiferal oozes, diatom tests are often dissolved. In weakly carbonaceous sediments, diatoms are found in profusion and without obvious traces of dissolution. Diatom content in these (sediments) sometimes reaches 10-20 million valves/g. In all cases, the carbonate material dilutes the numbers of diatoms in the sediments. For example, in the core extracted from a small area of foraminiferal oozes at station 4081 there were only 2.3 million valves/g; however, all around this station, in weakly siliceous oozes, there were from 11.3 to 18.4 million valves/g. In sediments at station 4081, solution by carbonaceous material has lowered the diatom content, compared with neighboring stations, by more than 5 times. Deeper than 4,500-4,800 m, carbonate sediments are absent, whereas diatom oozes are found at any depths if conditions are favorable for their accumulation.

In the distribution of diatoms on the ocean bottom, a relationship to climatic zones is visible. Diatom rich sediments occur in boreal, equatorial, and Antarctic regions of the ocean. All three regions have high productivity rates due to high nutrient salt content as a result of deepwater upwelling to the ocean surface. Diatoms require rich concentrations of biogenic elements: phosphates, nitrates, iron, and silica, to build cells during their growth period. Such conditions are found in cold waters of high latitudes. The zone of upwelling water in equatorial latitudes is also quite fertile for all ocean life, including diatoms. Equatorial waters are rich in diatoms, in spite of the general view of the cold-loving nature of these algae. This fact should be noted, because it indicates that there are cold-loving as well as warmth-loving species, and that the latter comprise a significant part of the present day diatom flora.

Species Composition of Diatoms in the Surface Sediment Layer of the Pacific Ocean

There is great interest, from the standpoint of the biogeographer, in the question of species composition of diatom flora in sediments of various ocean zones. The large amount of data accumulated during the last 10 years shows that the floral composition of diatoms varies most clearly relative to latitudinal zones of the ocean. In each zone, the composition of diatoms in the sediments depends on their location relative to the coast or the open ocean.

In the Pacific Ocean along a line extending from the northern margin of the Okhotsk and Bering Seas to the shores of Antarctica, sediments contain seven ecologically different complexes of diatoms (thanatocoenoses). These complexes correspond to defined diatom biocoenoses in plankton, but differ from them in species composition and quantitative interrelationships due to different decomposition rates of the species involved. These complexes are as follows: (I) Arctic-boreal, (II) Northern-boreal, (III) Subtropical, (IV) Tropical, (V) Equatorial, (VI) Subantarctic, and (VII) Antarctic.

Figure 3 shows the boundaries of distributions of all the listed complexes on the Pacific Ocean floor. The percentage content of species belonging to a designated ecological complex was calculated for each station. This (percentage) had always to be greater than 50%. In regions extremely poor in
18/ diatoms in the sediments, between 30° and 15°-10°N in the northern ocean basin and between 15° and 45°S in the southern, species found individually are denoted by symbols. Percentage content was calculated only in those cases where more than 200 valves could be counted in the samples.

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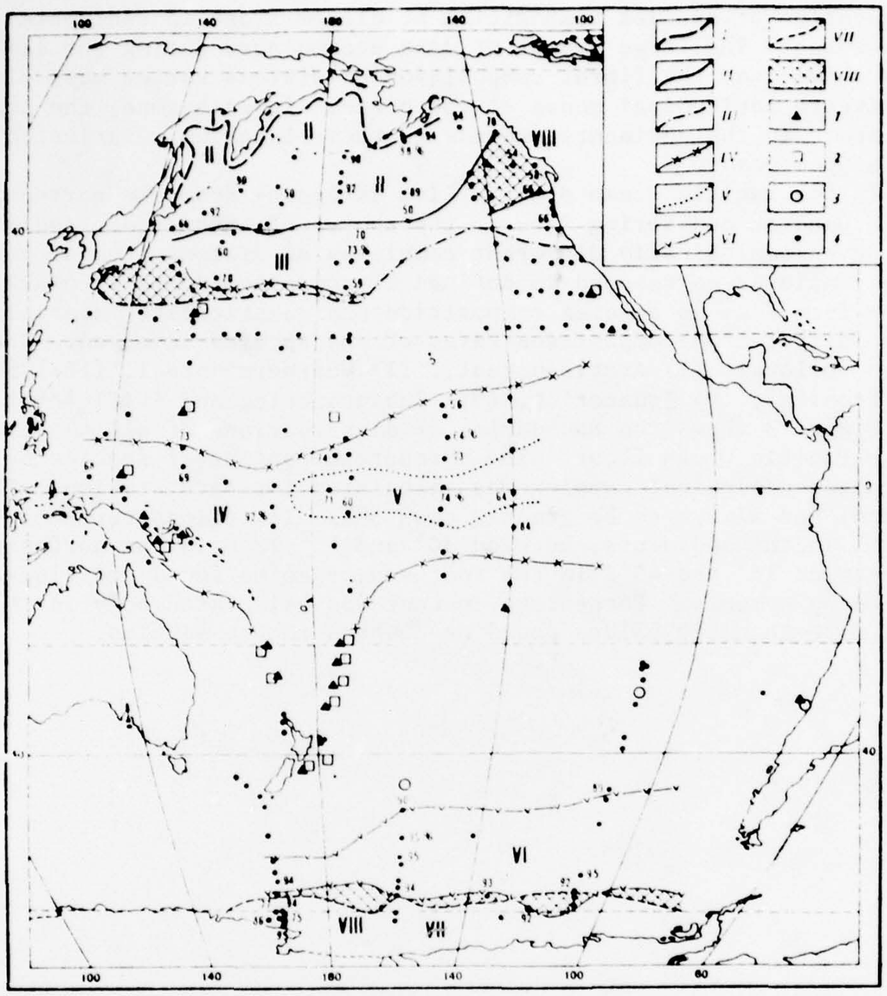

Fig. 3. Diatom complexes and their distribution in the surface sediment layer of the Pacific Ocean.

I - Arctic-boreal; II - Boreal; III - Subtropical; IV - Tropical; V - Equatorial; VI - Subantarctic; VII - Antarctic; VIII - complex of transitional type.

1 - individual finds of subtropical species; 2 - tropical; 3 - subantarctic; 4 - stations studied.

A diatom complex contains approximately 30 species. Noticeably greater species diversity can be observed in continental shelf sediments, where in addition to planktonic, there are also some benthic species. A particularly variegated species composition is peculiar to subtropical, equatorial, and Antarctic flora. In addition to the principal diatom complexes, one also
19/ can distinguish complexes of transitional type that contain elements of different ecological groups:

I. The Arctic-boreal diatom complex in sediments (fig. 4) consists of the following characteristic species: Melosira arctica Diekie, M. sulcata (Ehr.) Kutz., Thalassiosira nordenskioldii Cl., Th. hyalina Grun., Th. gravida Cl., Th. kryophila Jorg., Bacterosira fragilis Gran., Coscinosira polychorda Grun., Porosira glacialis Jorg., Chaetoceros furcellatus Bail., Ch. mitra Cl., Ch. subsecundus Hust., Fragilaria oceanica Cl., Fr. cylindrus Grun., Rhabdonema arcuatum var. ventricosa Grun., Coscinodiscus lacustris var. septentrionalis Grun., Biddulphia aurita Breb. et Godey, Rhizosolenia setigera Bright., Achnanthes taeniata Cl. In addition, in this thanatocoenosis one also frequently finds Navicula distans W. Sm., Trachyneis aspera (Ehr.) Cl., Diploneis subcincta Cl., D. interrupta Cl., Cocconeis costata Greg., Raphoneis surirella Grun., Triceratium arcticum Bright.

The Arctic-boreal diatom complex, confined to sediments of continental and island shelves in the Okhotsk and Bering Seas and to the northern margins of the Pacific Ocean, descends farthest southward near Hokkaido Island (figs. 7 and 9). The Arctic-boreal complex consists of neritic-glacial diatom flora, the most cold-loving elements of which are also known to exist in Arctic seas. In this context, one should mention Bacterosira fragilis, Porosira glacialis, Thalassiosira hyalina, Th. kryophila, Chaetoceros mitra, Coscinodiscus lacustris var. septentrionalis, a group of Arctic Fragiolariopsis (Fr. cylindrus, Fr. islandica, Fr. oceanica) and such typical cryophils as Melosira arctica, Achnanthes taeniata, and Triceratium arcticum. In shallow water coastal regions, the neritic planktonic species are joined by benthic forms of the sublittoral zone (Diploneis subcincta, D. interrupta, D. smithii). In fig. 3, the southern boundary of the Arctic-boreal diatom complex has been drawn from the distribution of Thalassiosira gravida and Bacterosira fragilis (total).

II. The northern boreal diatom complex (fig. 5) consists of the following characteristic species: Thalassiosira excentrica Cl., Stephanopyxis nipponica Gran et Jendo, Coscinodiscus curvatulus Grun., C. marginatus Ehr., Asteromphalus robustus Castr., Actinocyclus divisus (Grun.) Hust., A. ochotensis Jouse, A. curvatulus Grun., Rhizosolenia hebetata Gran (f. hiemalis), Rh. alata Bright., Thalassiothrix longissima Cl. et Grun., Denticula seminae Kanaya et Simonsen.

The region where masses of north-boreal diatoms are found in sediments fits quite well into the limits of subarctic water (figs. 7 and 9). At a series of stations, the content of north-boreal species within the complex comprises 90-94%. The overwhelming majority of species are typical representatives of plankton of open ocean regions. In its purest form the complex is found in sediments along the central section (180-162°W). In regions near Kamchatka and the Kuriles, the oceanic species complex is joined by the neritic diatoms Thalassiosira gravida Cl., Biddulphia aurita Breb et Godey, as well as Melosira sulcata (Ehr.) Kutz., which live in the near-bottom layers of shallow water regions.

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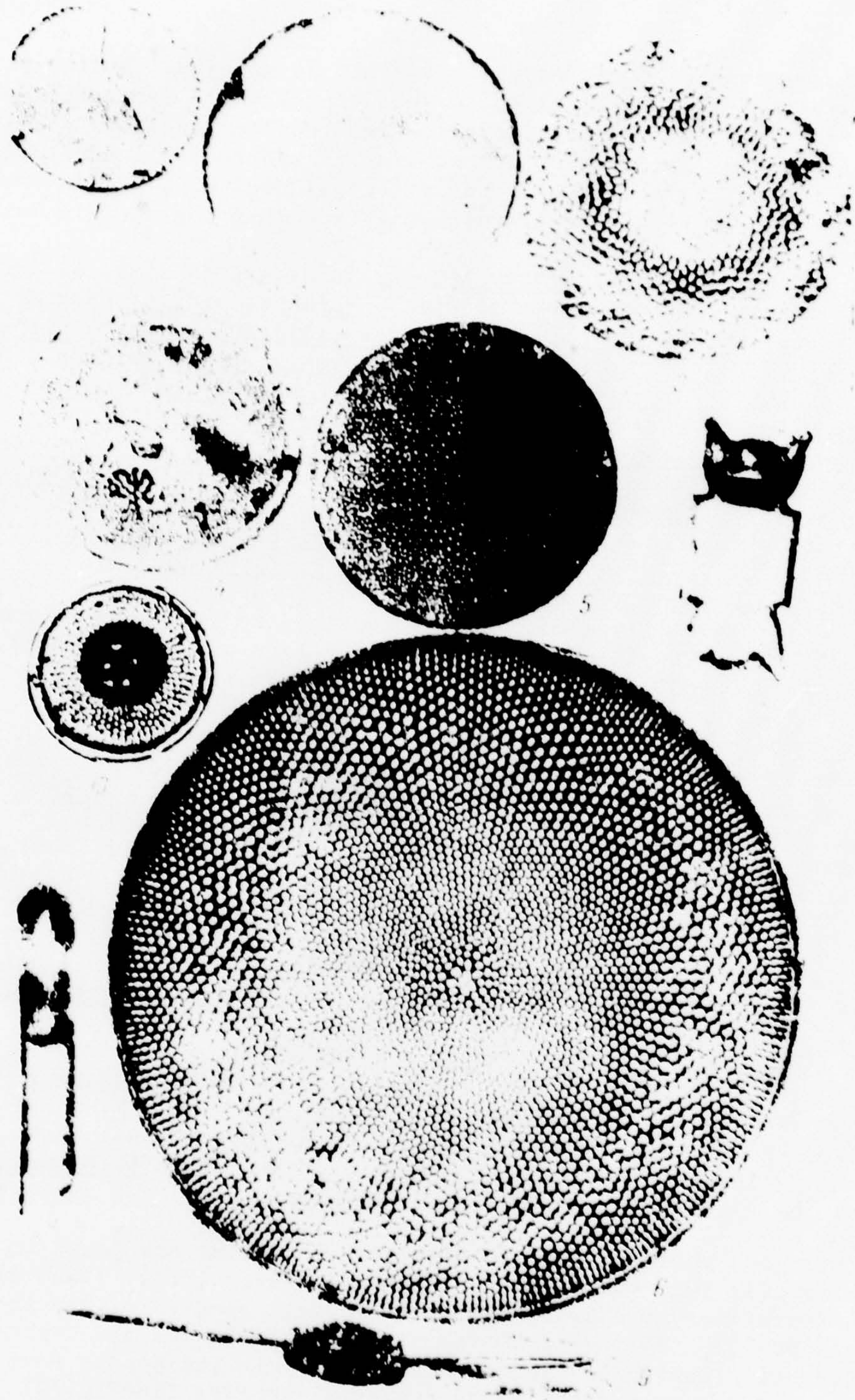

Figure 4. The Arctic-boreal diatom complex
1-Thalassiosira hyalina (Grun.) Gran; 2-Th kryophila (Grun.) Jorg.; 3-Th. gravida Cl.; 4-Porosira glacialis (Grun.) Jorg.; 5-Actinocyclus ochotensis Jouse; 6-Coscinodiscus oculus-iridis Ehr.; 7-Biddulphia durita (Lyngb.) Breb et Godey; 8-Rhizosolenia setigera Bright. (spore); 9-Chaetoceros furcellatus Bail.; 10-Bacterosira fragilis Gran (spore).

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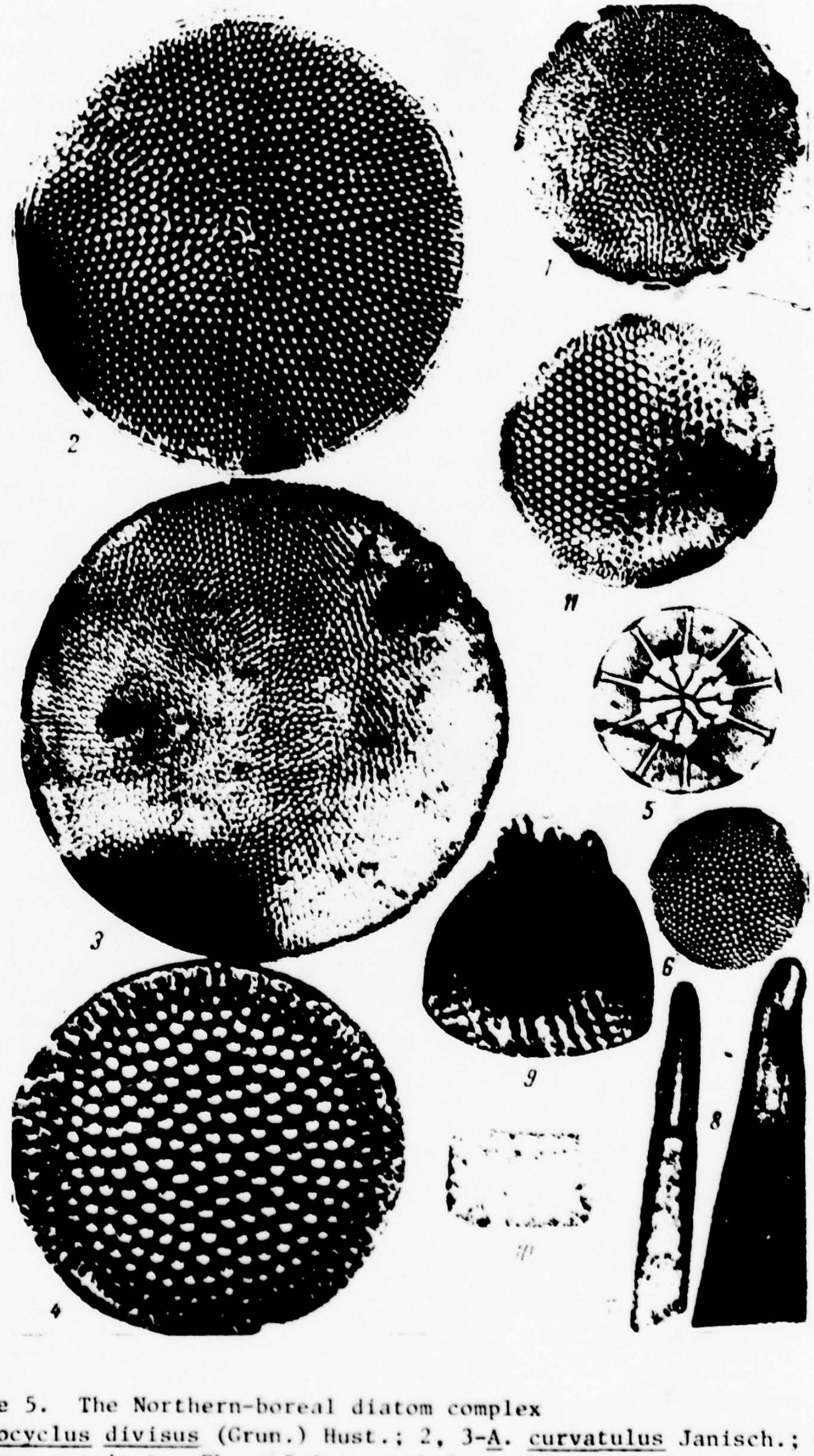

Figure 5. The Northern-boreal diatom complex
1, 6-Actinocyclus divisus (Grun.) Hust.; 2, 3-A. curvatulus Janisch.; 4-Coscinodiscus marginatus Ehr.; 5-Asteromphalus robustus Castr.; 7,8-Rhizosolenia hebetata (Bail.) Gran.; 9-Stephanopyxis nipponica Gran et Jendo; 10-Denticula seminal Simon. et Kanaya; 11-Thalassiosira excentrica (Ehr.) Cl.

The southern boundary of regions where north-boreal diatoms occur in large numbers is the northern boundary of the polar front. In the northwestern part of the ocean, it passes near 38°N, while near the North American coast, it rises to almost 55°N. In the west, the boundary shifts southward due to the influence of the cold Oyashio Current, which descends along the Kurile and northern Japanese islands.

At the convergence of the cold Oyashio and warm Kuroshio currents, is intensive horizontal and vertical intermixing of waters. The intermixed water forms the polar front--a transitional zone approximately 2°-4° wide.
22/ (Uda, 1963). The transitional zone is well defined by the diatom composition of sediments. Near its southern border, the content of north-boreal species drops to 50%. The diatom complex acquires a mixed character, i.e. it contains cold-water as well as warm-water species.

Transitional flora also occur in sediments near the northeastern margin of the ocean. Compared to western regions, all isotherms rise northward there. Consequently, transitional flora, which include a number of subtropical species, are formed there.

Warmth-loving diatoms, such as Pseudoeunotia doliolus, are found up to 50°N. At stations 4173 and 4142, the content of this species comprises 6% and 9.7%, respectively. Development of this species is facilitated by high surface water temperatures, which reach 15°C in summer. In the northwest part of the ocean, Pseudoeunotia doliolus is found in sediments only below 42°N, where it comprises approximately 2%. In the eastern part of the boreal zone, subtropical diatoms comprised approximately 50% at most stations between 50°-45°N (fig. 3).

Judging by the distribution of Denticula seminae in the sediments, one can assume that this species is more warmth-loving in nature. Maximum frequency of occurrence of Denticula seminae is shifted east of 160°W (46-66%) (fig. 6). In the west, the percentage of this species drops to 13-23%, except at station 3359 where it reached 53%.

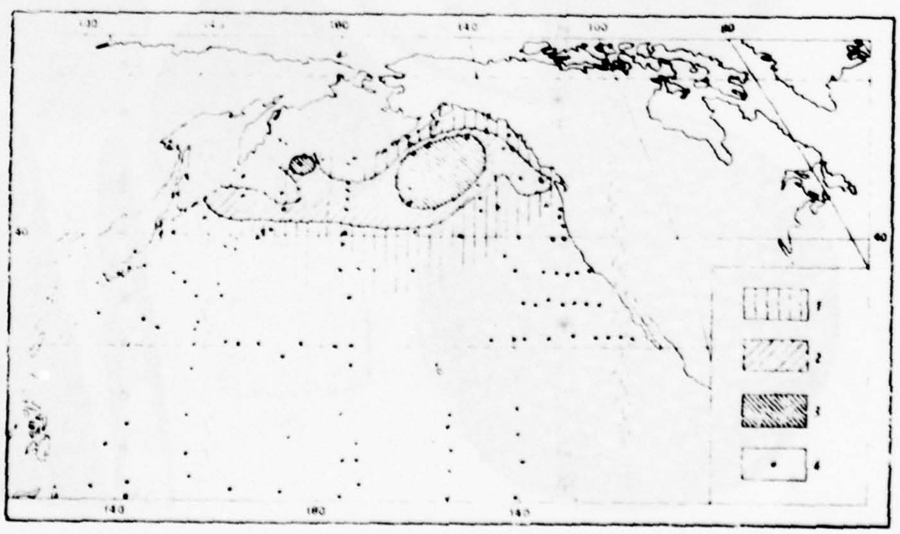

Figure 6. Distribution of Denticula seminae Simonsen et Kanaya in the surface sediment layer (in % of total quantity of diatoms)

1 - <10; 2 - 10-40; 3 - 40-70; 4 - stations studied.

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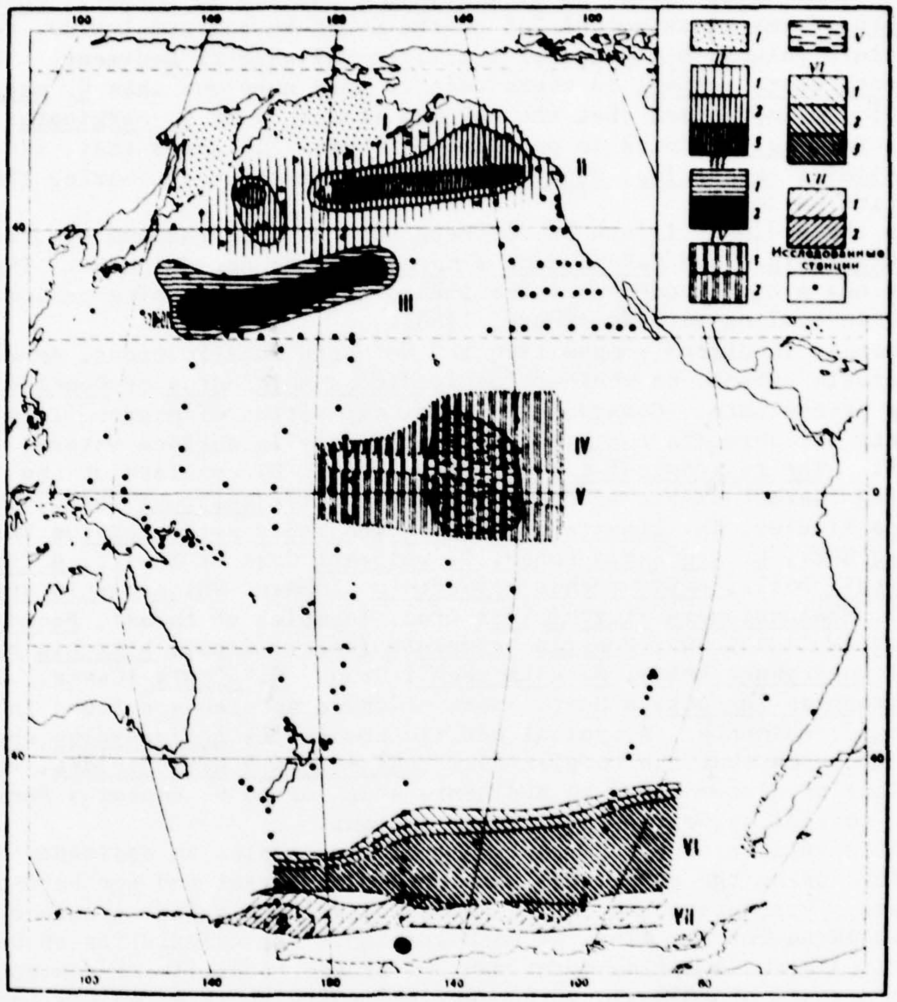

Fig. 7. Distribution of typical diatom species in the surface sediment layer (habitat regions)

I. Thalassiosira gravida Cl.; II - Coscinodiscus marginatus Ehr. (in % of total number of specimens): 1. <5; 2. 5-2; 3. <10-25; III Nitzschia sp. (complex): 1. <10; 2. 10-20; IV Hemidiscus cuneiformis Wall.; 1. <1; 2. 1-3; V Asteromphalus imbricatus Wall.; 1-3; VI Fragilariopsis antarctica Hust.; 1. 1-30; 2. 30-50; 3. 50-80; VII Fragilariopis curta Hust.; 1. <10; 2. 10-70. ☐ Stations studied.

Coscinodiscus marginatus occurs in greatest quantities in sediments east of 180°W (fig. 7). The distribution of Coscinodiscus marginatus in sediments clearly exhibits three zones: (1) 10 to 24% content, (2) 1 to 10% content, and (3) less than 1% content. The maximum content occurs in a strip between 50° and 45°N. South of 40°N, C. marginatus usually is absent. Coscinodiscus marginatus forms a maximum of 24% of the north-boreal complex or, converted to absolute values, a maximum of 1 million valves/g of sediment. The colonial
23/ form Denticulata seminal in every case is more numerous than C. marginatus. It should be emphasized that the maximum frequency of C. marginatus, unlike that of Denticula, occurs in pelagic sediments. It seems that, like Thalassiosica excentrica, Denticula occurs near the coast during the spring vegetation period.

In the sediment layers of northern regions, the maximum occurrence of Denticula seminae and Coscinodiscus marginatus do not coincide. The first species has a higher content in sediments related to warming periods, the latter--in cooling periods (Zhuze, 1963).

24/ Changes in diatom composition in the North Pacific Ocean, depend to a considerable extent, on whether Coscinodiscus marginatus or Denticula seminae predominate. Consequently, the composition of diatom flora in sediments reflects its contemporary specificity in surface waters.

III. The subtropical diatom complex (fig. 8) consists of the following characteristic species: Thalassiosira decipiens Jorg., Th. japonica Kiselev, Th. lineata Jouse, Coscinodiscus asteromphalus Ehr., C. radiatus Ehr., C. stellaris Roper, C. wailesii Gran et Angst., Actinocyclis ehrenbergii Bail., Actinotychus bipunctatus Lohman, Rhizosolenia styliformis Bright., Thalassionema nitzchioides Grun. (complex of forms), Pseudoeunotia doliolus (Wall.) Grun., Roperia tesselata (Roper) Grun., Nitzchia bicapitata Cl., N. interrupta Heid., N. kolaczeckii Grun., N. sicula (Castr.) Hust., Thalassiothrix lanceolata Hust. Most of these species are found in profusion in pelagic sediments. A typical neritic species is Actinocyclus ehrenbergii Bail. It seems that the complex form Thalassionema nitschioides, which is so typical of diatom flora in sediments south of 40°N, contains forms that live in coastal, as well as in pelagic regions.

The distribution of the subtropic diatom complex in sediments was determined using the same method as for Arctic-boreal and northern-boreal complexes. Percentage content of all principal ecological groups of diatoms was calculated for the flora at each station. The calculation showed that subarctic diatoms comprise more than 50% of the total floral content in sediments south of 40°N along the section 160°E, south of 43°N along the section 176°W, and south of 45°-47°N along the section 130°W (fig. 3). Consequently, the northern boundary of high occurrence of subtropical species is also the southern boundary of north-boreal species.

The southern boundary of the complex discussed in sediments can be determined only very approximately. In the section along 155°-160°E, subtropical diatoms predominate up to 23°N. This group of species comprises 60-70% of the total flora there. Along this section, the last station with subtropical species content higher than 50% was located at about 30°N. Farther south, in red clays, individual diatoms occur. The farther east toward the ocean margins, the less reliable become data on relative percentages of different diatom complexes. An extensive region, practically free of diatoms exists between 40° and 25°N and east from 170°W to the coast of North America.

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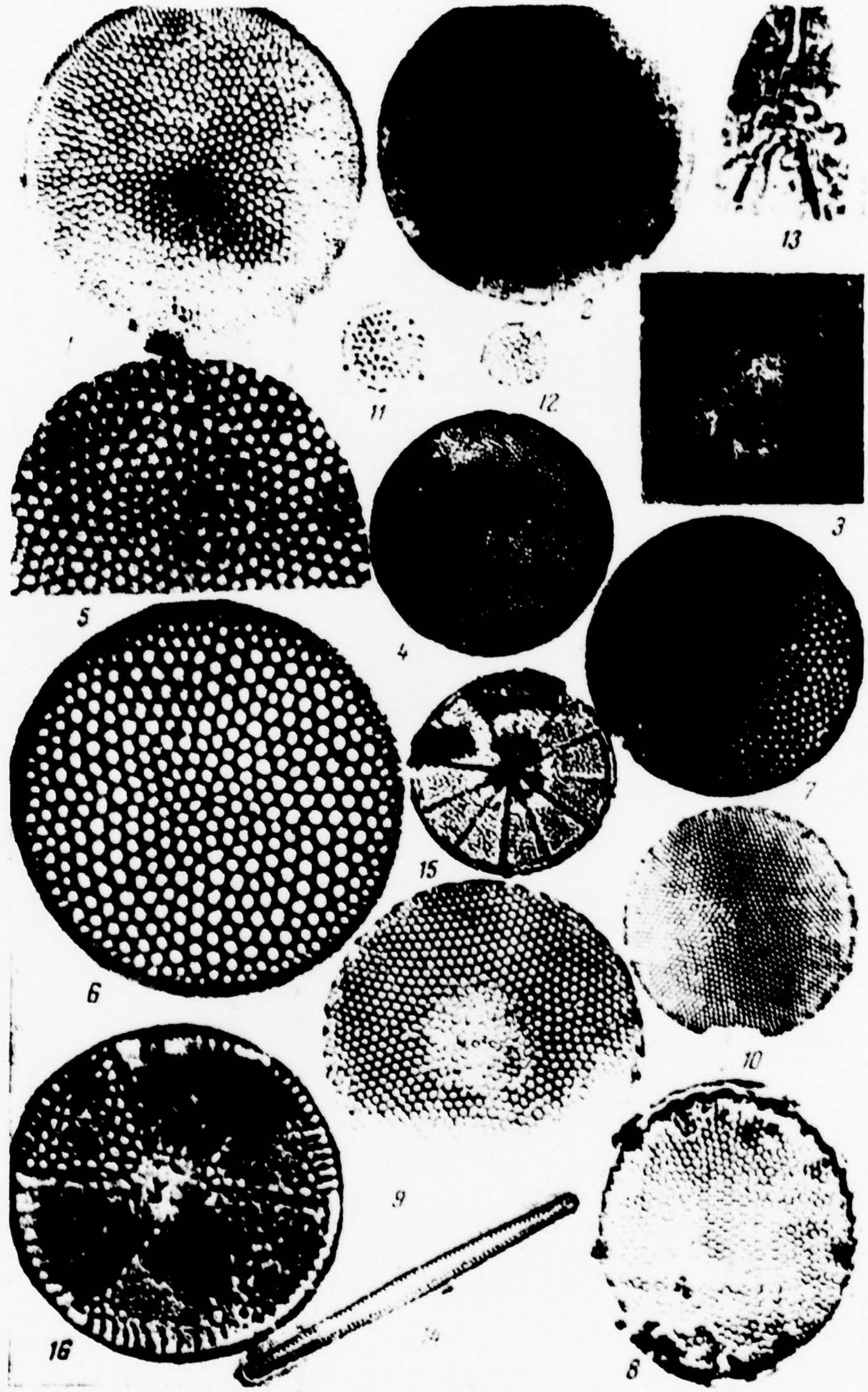

Figure 8. The subtropical diatom complex

1-Roberia tesselata (Rop.) Grun.; 2,3-Coscinodiscus stellaris Roper; 4,5-C. asteromphalus Ehr.; 6,7-C. radiatus Ehr.; 8-Roperia tesselata f. ovata (Mann.) Heid.; 9,10-Thalassiosira pacifica Gran et Angst.; 11,12-Th. decipiens (Grun.) Jorg.; 13-Rhizosolenia styliformis var. latissima Bright.; 14-Thalassionema nitzschioides Grun.; 15-Actinoptychus bipunctatus Lohman; 16-A. undulatus (Bail.) Rolfs.

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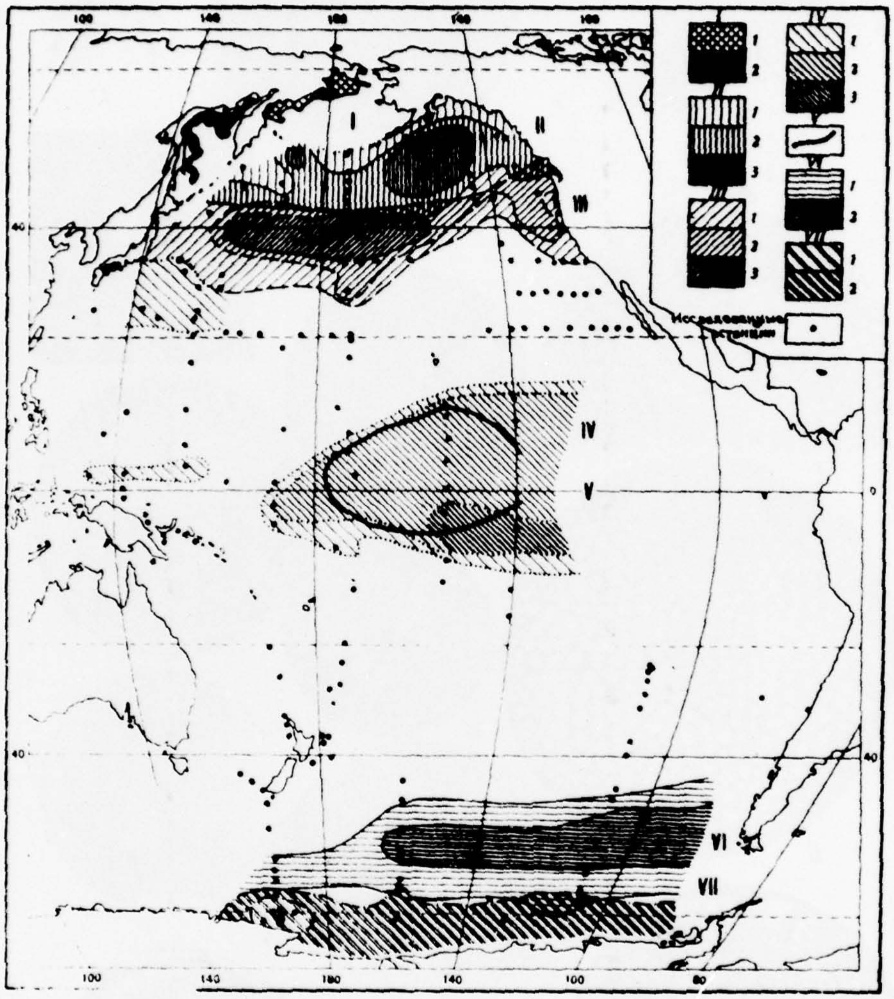

Figure 9. Distribution of typical diatom species in the surface sediment layer (habitat regions) (in % of total number of specimens)

I-Bacterosira fragilis Gran; 1. 1-10; II-Denticula seminae Simonsen et Kanaya; 1. 1-10, 2. 10-40, 3. 40-70; III-Pseudoeunotia doliolus Grun.; 1. 5, 2. 5-10, 3. 10-25; IV-Coscinodiscus nodulifer A.S.; 1. 1-10, 2. 10-20, 3. 20-50; V-Coscinodiscus africanus Janisch.; 0.2-1.4; VI-Coscinodiscus lentiginosus Janisch.; 1. 3-15, 2. 15; VII-Eucampia balaustium Castr.; 1. 1-5, 2. 5-40

[o] stations studied

24/ At most stations south of 40°-45°N, subtropical species predominate among the diatoms in sediments. They usually comprise above 44-60% of them. The range center of the most typical species is located here; as indicated by their maximum occurrence here. Consequently, the environment of the subtropical zone most favors growth of this numerous group of species. Naturally, a question arises as to just which diatoms comprise the remaining 45-30% of the total quantity of valves. If analyses of diatoms near the northern boundaries of the region are studied, one discovers that these latter are mainly northern-boreal cold-loving species. For example, at station 3155 on the boundary between the two zones, subtropical species comprise 62%, the north-boreal share is 32%, tropical - 6%, and sublittoral - about 2%. At station 3495, near the subtropical convergence zone, the proportions in the complexes are as follows: subtropical - 65.4%, tropical - 26.3%, north-boreal - 5.3%, sublittoral benthos - 1.9%.

26/ The distribution of the subtropic diatom complex in the surface sediment layer is very obviously related to the direction of the main flow of the Kuroshio. The range centers of many subtropical diatoms are typical of regions east of Japan (south of Hokkaido Is.) (fig. 9). Similar situations exist also in the central regions near 174°W, but changes off the coast of North America. There were enough diatoms to calculate the proportion of each species at only 5 stations there, and the subarctic complex accounted for 46.5 to 68.5% of the total.

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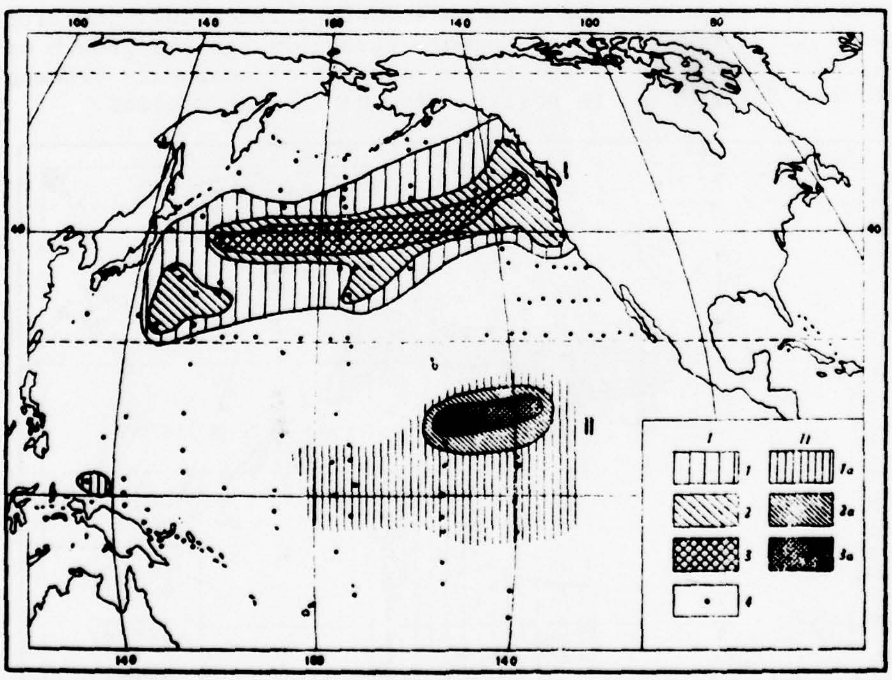

Fig. 10. Distribution of Thalassiosira decipiens (Grun.) Jorg. (I) and Th. oestrupii (Ostf.) Pr.-Lavr. (II) in the surface sediment layer (in % of total quantity of specimens)

1 and 1a = 1-5%; 2 and 2a = 5-10%; 3 and 3a = 10-30%; 4 = stations studied.

Charts compiled for the species Thalassiosira decipiens and related forms (fig. 10) illustrate subtropical species distribution in the surface sediment layer. The range center of Thalassiosira decipiens is within the area delineated by isolines showing 15% to 30% species content. This region forms a strip between 40° and 37°N in the western and central regions of the ocean. This isoline rises to almost 50°N in the eastern regions, following the distribution of other reasonably warmth-loving species.

The distribution region of the closely related Thalassiosira oestriepii (Ostf.) Proch-Lavr., is delineated in fig. 10. This species is distributed in the equatorial region, east of 176°W. Th. oestrupii (Syn. Coscinosira oestrupii Ostf.) differs from Th. decipiens Jorg. by two rods on the valve at a considerable distance from each other. Hasle (1960), who studied the structure of Th. decipiens, considers one rod to be the most typical feature of this species. Thalassiosira oestrupii differs also by its large size and the sharp facet between the middle and the peripheral parts of the valve. Differences between the size of the areolae on the valves are more sharply pronounced than in Th. decipiens (Zhuze, 1968a). These species also differ in distribution in the sediment layer. For example, at station 3155 and 3156, Th. oestrupii occurs in interglacial sediments, while Th. decipiens Th. decipiens is found in volume in Holocene sediments and disappears in interglacial sediments.

Another species with its range center in subtropical regions is Pseudoeunotia doliolus, which comprises from 20% to 26% of the sediments south of 40°N. Near the coast of North America its content averages 9% (fig. 11). The content of Pseudoeunotia among diatoms in equatorial sediments region
28/ is 5%, and only at 4 stations does this content reach 10%. Apparently, subtropical water temperatures are more favorable for the growth of this species. Its proportion of the floral content of sediments between 30°-40°N is 20-26% and determines its position as the leading species.

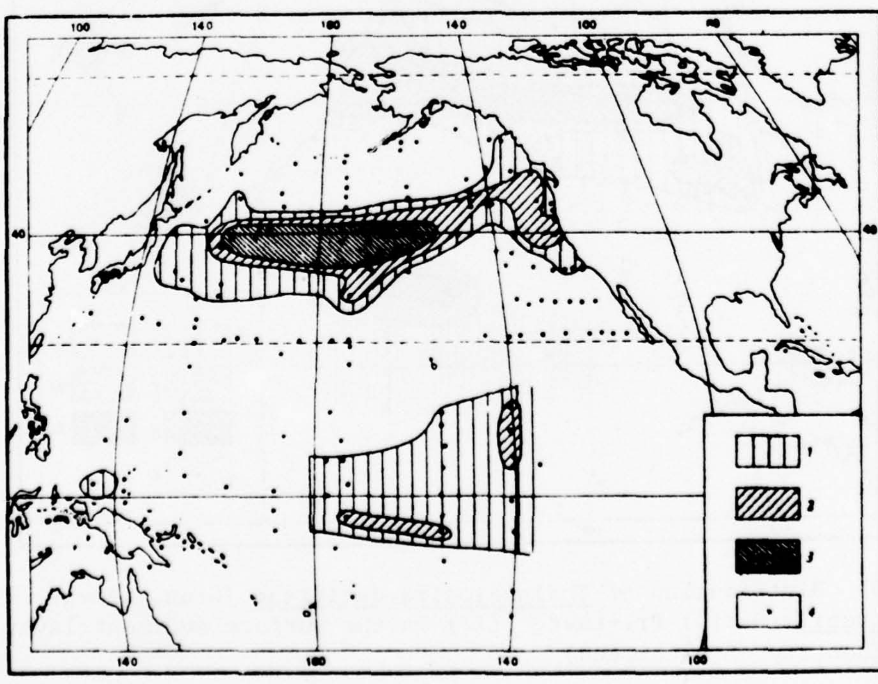

Fig. 11. Distribution of Pseudoeunotia doliolus Grun. (in % of the total number of specimens)
1) - 1-5%; 2) - 5-10%; 3) - 10-25%; 4) stations studied.

Nitzschia spp (N. bicapitata, N. interrupta, N. koloczekii and N. sicula) also have the same type of range. Their habitat is found typically in sediments south of 40°N (fig. 12). The maximum occurrence of Nitzschia spp. is found between 36° and 40°N (fig. 12). North of 40°, these warm-water Nitzschia species are unknown in sediments. At two stations (4081 and 4084), the content of Nitzschia in the flora is 15.4% and 16.9%. Near the subtropic convergence zone, at station 4362, the proportion of this group of Nitzschia increases to 15%. In the eastern regions of the ocean it does not exceed 2%, while in the equatorial zone it ranges from 0.3% to 1.9%. A high proportion (up to 10.5%) near the equator was noted at station 3646. Individual valves of Nitzschia bicapitata and N. sicula were found in sediments north of New Zealand. In the Indian Ocean, the same complex of Nitzschia species is typical of temperate latitudes of the southern hemisphere and the entire northern tropics.

The quantitative maximum in the sediment zone between 40° and 23°N is also typical of the range of Thalassionema nitzschioides Grun. and its variety obtusa Heid, one of the most numerous species in the subtropics. In the center of its range, Thalassionema comprises 20% to 40%. Near the coast of North America, Th. nitzschioides content does not drop below 20% and the average is 25%, but at one station it was 40%. In the West Pacific
29/ Ocean, Thalassionema nitzschioides is abundant in sediments almost up to Subtropical Convergence (maximum 36.5% and on the average 17% of the floral content). The farther south, the more pronounced are deviations from the

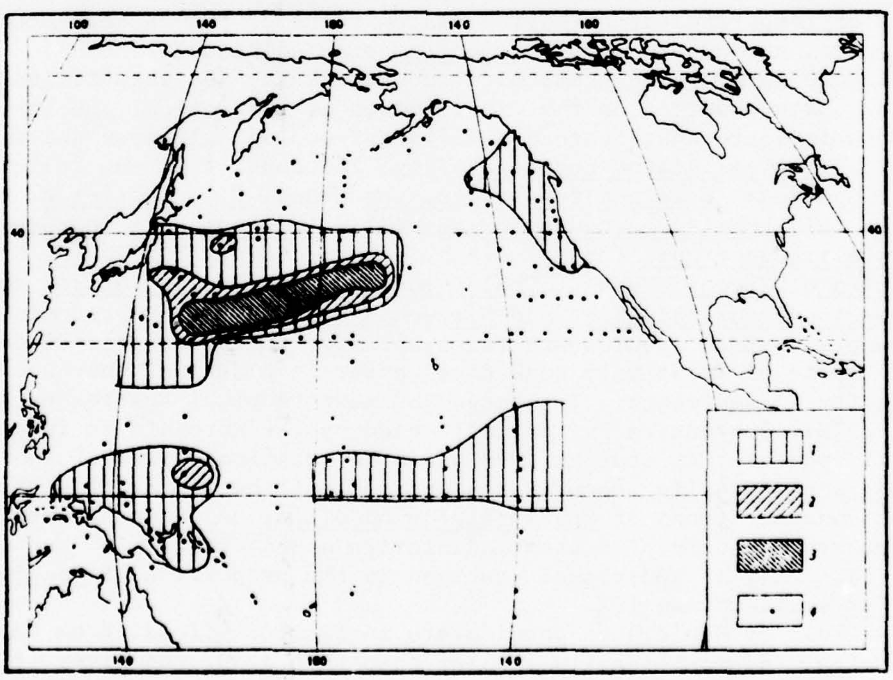

Fig. 12. Distribution of Nitzschia species (N. bicapitata, D. sicula, N. braarudii) in the surface sediment layer (in % of the total number of specimens).

1) - 1-5% 2 - 5-10%; 3) - 10-20%; 4) stations studied.

typical form of Thalassionema nitzschioides Grun. Thalassionema nitzschioides var. parva Heid. is found coincident (with the above species).

The subtropical and equatorial zones are partially inhabited by different ecological forms of Thalassionema. In the future it will be necessary to determine the independence of all species found. It is important to point out the obvious morphologic features of Thalassionema living in waters between 40° and 30°N and near the equator. It would be a mistake to combine all the diverse forms of Thalassionema nitzschioides Grun. into a single typical form.

One should especially emphasize the taxonomic and, probably, ecological individuality of Thalassionema nitzschioides var. parva Heiden. *In its* range, it increases in sediments south of 40°N, with the maximum occurring in the western part of the ocean (at st. 4449-25%). The distribution of this form in the equatorial zone is characterized by similar gradations.

To complete the characteristics of the subtropical complex, one must add data on the distribution of species such as Rhizosolenia styliformis, Coscinodiscus wailesii, C. radiatus, and a number of others. Coscinodiscus radiatus, is a species which, in the sediment layer north of 40°N, appears in horizons corresponding to warming periods. Usually its maximum appears in horizon III, which corresponds to an interglacial epoch. Data on the
30/ contemporary distribution of this species show that its range center is south of 40°N. At all stations, the proportion of Coscinodiscus radiatus did not exceed 10%, and it does not form mass accumulations in the surface sediment layer. Individual finds have been made far to the north in the Gulf of Alaska and near the Aleutian Islands. The contemporary distribution of C. radiatus has features similar to C. asteromphalus. Both species are typical of temperate warmth-loving diatom flora of the Pacific Ocean; in the tropics, encounters with C. radiatus are individual.

Diatoms forming the subtropical complex have been insufficiently studied. Data obtained on the distribution of subtropical species in sediments indicate that there are different ecological races and varieties.

IV. Tropical diatom complexes (fig. 13) consist of the following typical species: Coscinodiscus crenulatus Grun., C. nodulifer A. S., C. lineatus Ehr., Hemidiscus cuneiformis Wall., Planktoniella sol Schutt., Thalassiosira oestrupii (Ostf.) Prosh. - Lavr., Nitzschia marina Grun., Rhizosolenia bergonii Perag., Thalassionema spp., Thalassiothrix spp.

Coscinodiscus nodulifer and Nitzschia marina usually predominate in this complex. Both species are remarkable for their exceptional durability, and, in spite of relatively weak development in plankton, they accumulate in quantity in sediments. The ranges of most tropical species extend north to 30°-35°N. The entire region influenced by the Kuroshio is inhabited by tropical species. At station 5098 and other stations south of the equator, Coscinodiscus nodulifer comprises almost 50% of the flora. However, the highest concentrations of Coscinodiscus nodulifer occur in sediments at the northern boundary of diatom-radiolarian oozes, between 5° and 15°N (fig. 14). Only at individual stations is the proportion of Coscinodiscus nodulifer smaller than 10%.

The role of Hemidiscus cuneiformis in tropical flora, from the quantitative view, is significantly smaller than that of C. nodulifer (fig. 7). Its principal range in sediments is limited to the region of diatom-radiolarian oozes. In the total floral composition of diatoms, the proportion of Hemidiscus cuneiformis does not exceed 5%. In the central section, individual Hemidiscus cuneiformis is found to 40°N.

31/

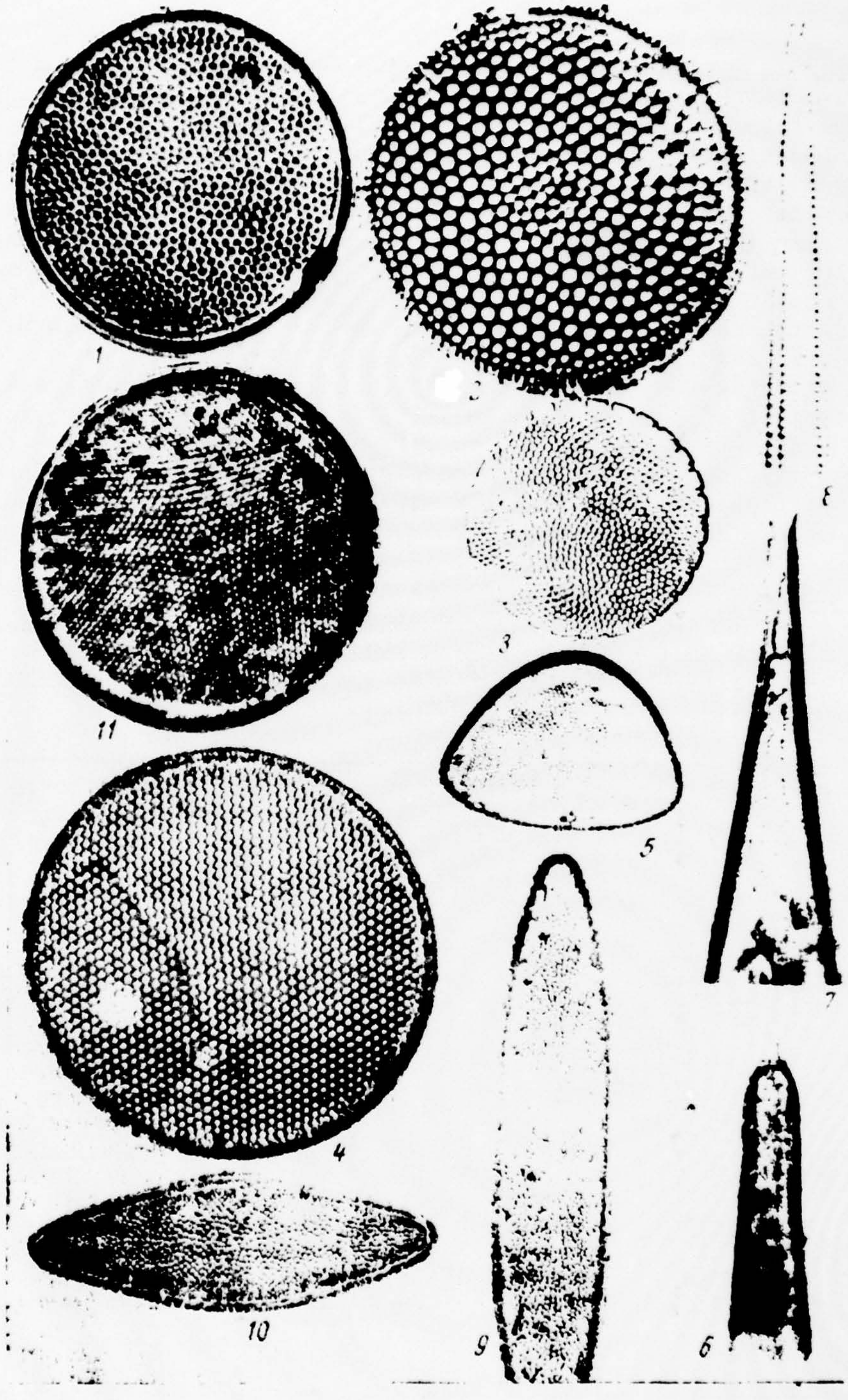

Fig. 13. Tropical and equatorial diatom complex
1 - Coscinodiscus africanus Janisch; 2 - C. nodulifer A. S.; 3 - C. crenulatus Grun.; 4 - C. lineatus Ehr.; 5 - Hemidiscus cuneiformis Wall.; 6 - Rhizosolenia firma Karst.; 7 - Rh. bergonii Perag.; 8 - Nitzschia marina Grun.; 9 - Actinocyclus ellipticus v. elongata Kolbe; 10 - A. ellipticus v. lanceolata Kolbe; 11 - Planktoniella sol (Wall.) Schutt

Nitzschia marina predominates in sediments between 15°N and 5°S (fig. 15). In this extensive region the amount of Nitzschia marina is more or less uniform and ranges from 10% to 22%. In the eastern regions of the ocean the species is distributed almost to 40°N and generally follows the main flow of the Kuroshio.

Fragments of Ethmodiscus rex Wallich have been found in all tropical sediment samples examined. It is very hard to quantitatively evaluate Ethmodiscus fragments. The largest deposits of fragments in sediments occurred east of 160°E, at stations 3634, 3997, 4000, and 4003. Relatively high concentrations of Ethmodiscus fragments were found at equatorial stations 5113 and 5114 in the central section (fig. 1).

Not stopping to describe the distribution regions of many species of diatoms typical of the tropics, we will limit ourselves to the statement that the ranges of Planktoniella sol, Coscinodiscus crenulatus, C. lineatus, Thalassiothrix spp. have similar boundaries. The southern boundary of rich deposits of tropical diatoms approximately follows 5°S. The region south of the boundary of the distribution of carbonate sediments is devoid of diatoms.

V. The Equatorial diatom complex consists of the following typical species (fig. 13): Asteromphalus imbricatus Wall., Coscinodiscus africanus
31/ Janisch, Rhizosolenia firma Karst., Actinocyclus ellipticus Grun. and its varieties, Triceratium cinnamomeum Grev., Thalassionema sp., Asterolampra marylandica, Ehr.

32/

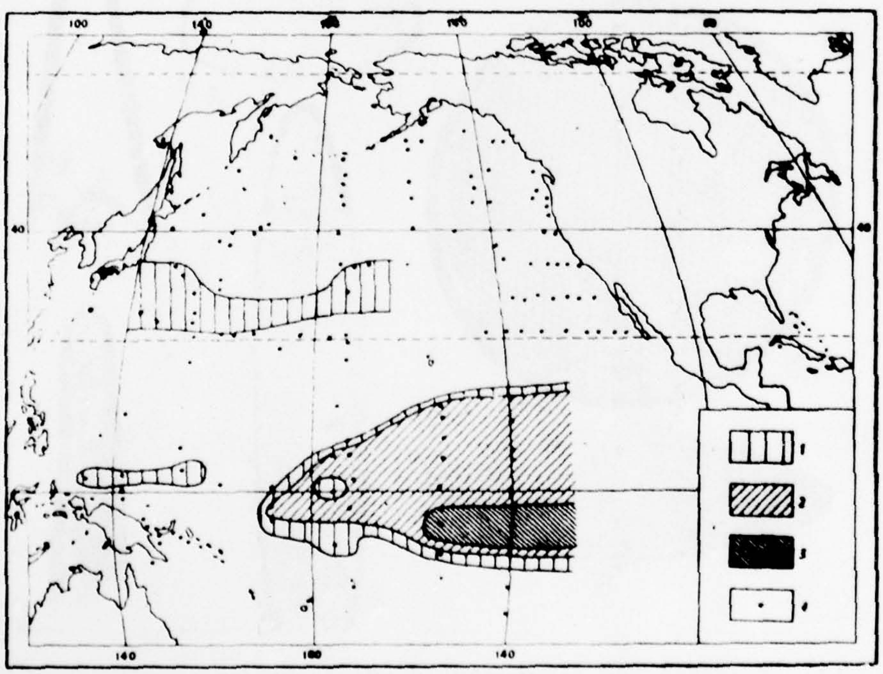

Fig. 14. Distribution of Coscinodiscus nodulifer A. S. in the surface sediment layer (in % of the total quantity of sample).

1. 1-10%; 2. 10-30%; 3. 30-50%; 4. stations studied.

33/

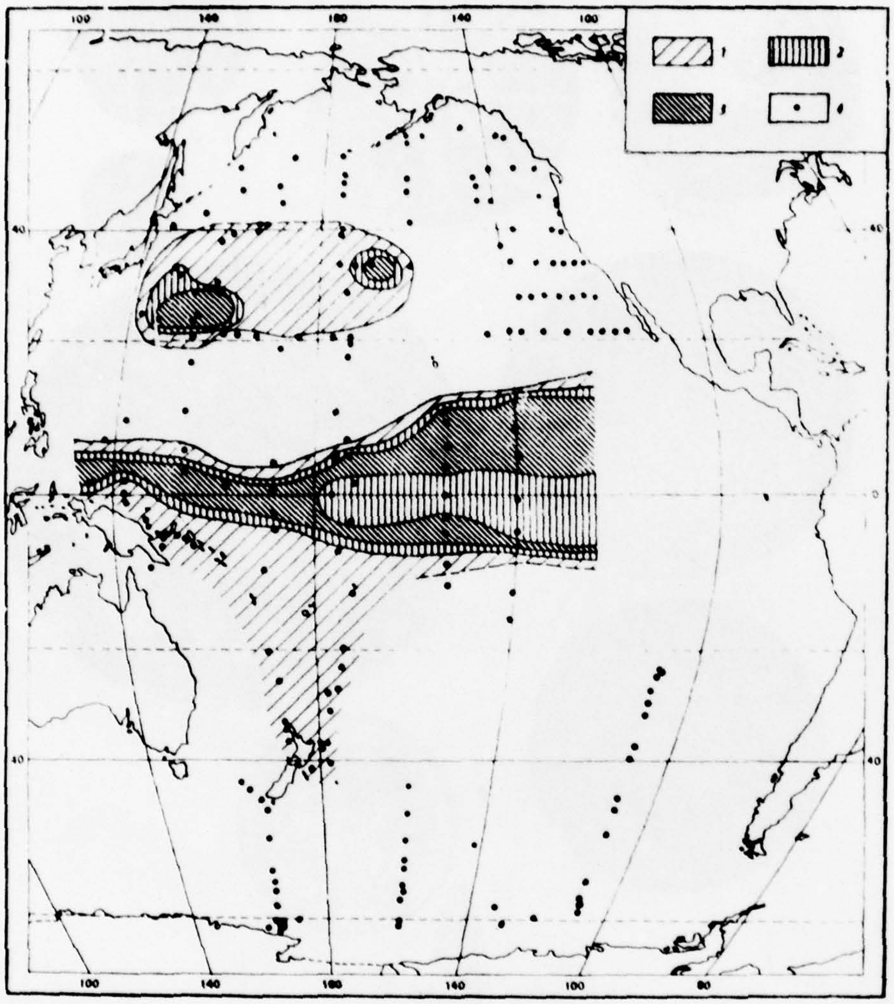

Fig. 15. Distribution of Nitzschia marina Grun. in the surface sediment layer (in % of the total quantity of sample)

1. 1 to 5%; 2. 5-10%; 3. 10-22%; 4. stations studied.

34/

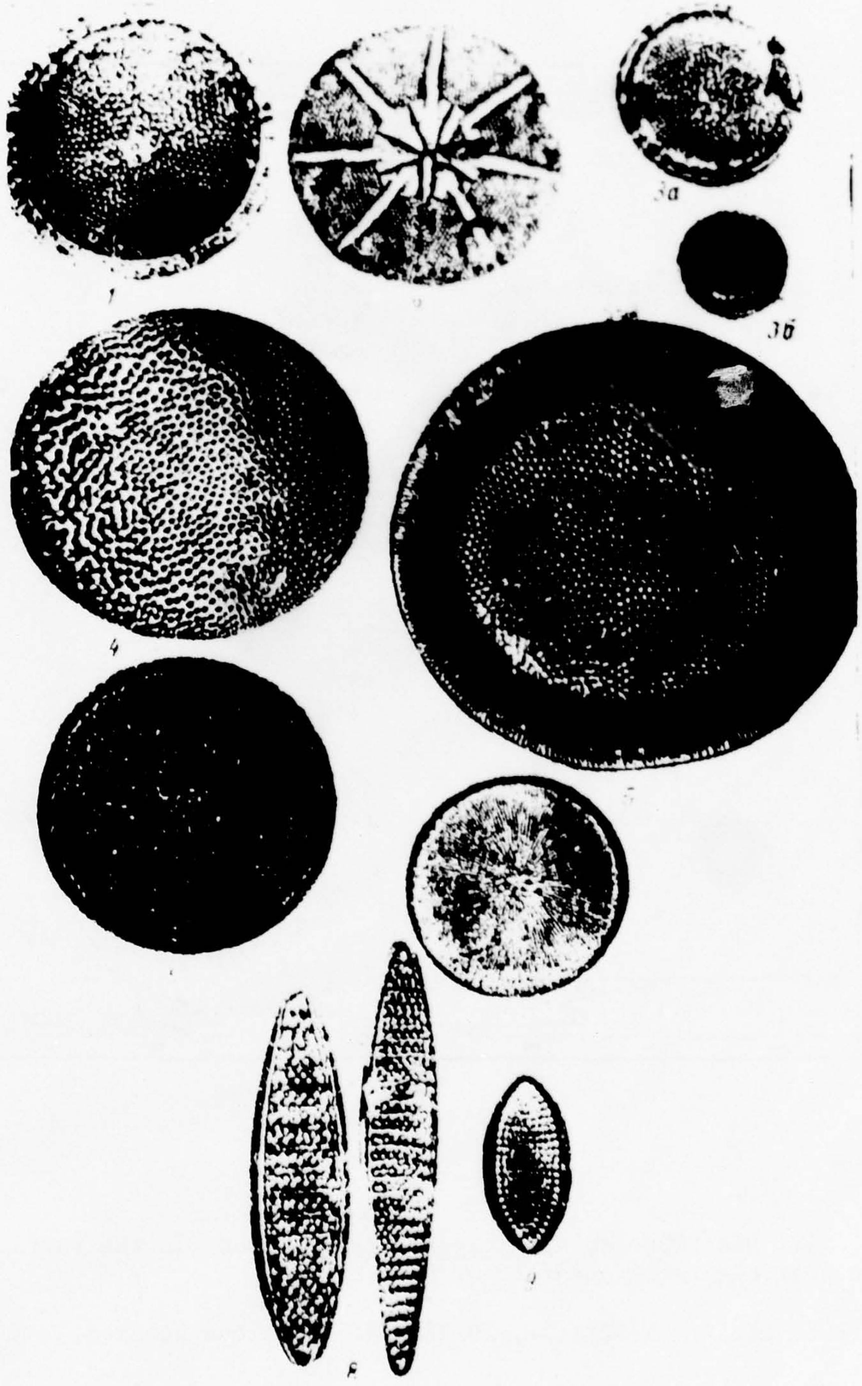

Fig. 16. The subantarctic diatom complex.

1 - Schimperiella antarctica Karst.; 2 - Asteromphalus hookeri Ehr.; 3a, b - Thalassiosira gracilis Hust.; 4, 5 - Coscinodiscus lentiginosus Janisch.; 6 - Schimperiella antarctica Karst.; 7 - Coscinodiscus furcatus Karst.; 8 - Fragilariopsis antarctica (Costr.) Hust.; 9 - Fr. separanda Hust.

32/ This complex typifies a strip of sediments between 5°N and 4°S in the western regions and between 15°N and 7°S in the eastern part of the ocean. Thus, the equatorial complex is confined to diatom and carbonate muds of the productive equatorial zone of the Pacific Ocean. In the east, the distribution belt of this complex is approximately 2.5 times wider than in the west. It is possible that some species of the complex are endemic to equatorial waters. From the point of biogeographical regionalization, this group of diatoms is of special interest, although the proportion this group forms of the total tropical flora is quantitatively small. The ranges of two species of the equatorial complex are shown in figs. 7 and 9.

In addition to the species mentioned, diatoms whose systematic features remain obscure (the (species Thalassiosira, Asteromphalus, Asterolampra, and Nitzschia), are found in equatorial zone sediments. A vast area of sediments between 5° and 45°S is a region poor in diatom remains, where detached members of tropical and subtropical complexes occur. Thus, the diatom composition of sediments of the South Pacific to about 45°S, has no specific features. For example, near North Island, New Zealand (station 3839), tropical species, Planktoniella sol, Hemidiscus cuneiformis, Nitzschia
33/ marina, Rhizosolenia bergonii, and the subtropical species, Thalassionema nitzschioides var. parva, Thalassiosira decipiens, and Nitzschia interrupta, have been found in the sediments. Percentage correlation between these species was not determined.

Seventeen diatom fragments belonging principally to subtropical species were found at station 3825 (25°S). However, individual fragments of Fragilariopsis antarctica, a subarctic species that penetrates far north of the Antarctic convergence zone, were found in the same region.

According to meager existing data, diatom flora south of the southern subtropical convergence zone has transitional features. North of this zone, exclusively tropical species are found, but to the south are both tropical and subtropical forms. In the central section of the ocean, these species are joined by individual elements of subantarctic diatoms.

35/ VI. The Subantarctic diatom complex consists of the following typical species (fig. 16): Fragilariopsis antarctica (Costr.) Hust., Coscinodiscus lentiginosus Janisch.; Thalassiothrix antarctica Cl. et Grun., Schimperiella antarctica Karst., Coscinodiscus bullatus Janisch., C. inflatus Karst., C. tumidus Janisch., Asteromphalus hookeri Ehr., A. parvulus Karst., A. hyalinus Karst., Coscinodiscus kolbei Jouse, C. tabularis Grun., C. gyratus Janisch., Rhizosolenia hebetata Gran., R. hebetata forma bidens Karst., Chaetoceros dichaeta Ehr., Hemidiscus karstenii Jouse, Actinocyclus radiatus Rattray. This list does not contain species that, because of their rapid rate of decomposition, are rarely found in sediments (Dactyliosolen antarctica Castr., Chaetoceros cryophilum, Tropidoneis antarctica, and the species group Nitzschia.

As the subantarctic region, we mean the region south of the Antarctic convergence zone. The southern boundary of this region is the Antarctic Divergence Zone, i.e., region where the eastern and western drift divides, as defined by geographers and climatologists. Unlike these, biologists define the subantarctic region as lying north of the Antarctic Convergence. This terminology has unfortunately taken root in the biological literature, and impedes mutual understanding and creates unnecessary difficulties. Based on climatic zones of the Southern Ocean, the subantarctic zone of the biogeographers should be assigned to the temperate belt or to the notal region. The maximum content of Antarctic species occur in diatom oozes.

35/ Based on their degree of concentration in sediments, such mass species as Fragilariopsis antarctica, Coscinodiscus lentiginosus, Schimperiella antarctica, and Thalassiothrix antarctica are the sediment forming species in the region of accumulation of Antarctic diatom ooze.

In the Pacific Ocean, subantarctic diatoms consist of the same species as in the Indian and Atlantic ocean sectors of the Antarctic. The circumpolar distribution of most subantarctic diatoms is explained by the stability of the environment and the continuous movement of the main water masses, including deep water, around the continent (Kamenkovich, 1962). This is also true to the same degree in the distribution of the Antarctic diatom complex. The content of subantarctic diatoms in the flora at each station was calculated in percent. The northern boundary of dominance of subantarctic diatoms at 58°S follows the New Zealand section at 55-54°S, follows the central section, and rises to 50°S near 110°W (fig. 3). The proportion of this species complex ranges from 85 to 97%. It does not drop below 85% at any station. The northernmost point of the subantarctic complex is at station 419. At stations 402 and 404, near the southern polar (Antarctic) circle, this complex comprises 94-95% of the content.

The ranges of the most typical subantarctic species, Fragilariopsis antarctica and Coscinodiscus lentiginosus, are shown in figs. 7 and 9. The range centers of these species are in the open ocean, in the diatom ooze zone, where Fragilariopsis comprises from 60% to 79%.

The distributions of Coscinodiscus lentiginosus and Fragilariopsis antarctica generally coincide, but the proportion of the former species in sediments is lower than that of Fragilariopsis antarctica[1]. The maximum content of C. lentiginosus is 21-23%. In shelf sediments, along King George
36/ V Coast, the content of both species drops to 1-9%. North of 58°S, the quantity of Fragilariopsis gradually decreases, but individual occurrences of this species were noted in sediments of temperate latitudes (40°-30°S). One should emphasize the exclusive aspect of the subantarctic diatom flora, which is characterized by almost 100% endemism.

VII. The Antarctic diatom complex (fig. 17) consists of the following typical species (in the following list the species appear in the order of magnitude of their quantitative content in the sediments): Fragilariopsis curta Hust., Fr. cylindrus (Grun.) Helmcke et Krieger, Fr. sublinearis (Grun.) Helmcke et Krieger, Eucampia balaustium (Costr., Thalassiosira gracilis (Karst.) Hust., Th. antarctica Comber, Charcotia actinochilus (Ehr.) Hust., Coscinodiscus furcatus Karst., C. oculoides Karst., C. symbolophorus Grun., Biddulphia weissflogii Janisch., Porosira pseudodenticula (Hust.) Jouse. There are only 38 species in the Antarctic plankton complex.

All these species are typical and endemic representatives of glacial neritic flora of the Antarctic zone. Most of these species gravitate to sediments of the shelf and continental slope (Fragilariopsis curta, Biddulphia weissflogii, Porosira pseudodenticulata, Coscinodiscus symbolophorus), whereas other species of the complex are distributed more widely and enter the open ocean regions (Eucampia calaustium, Charcotia actinochilus, Coscinodiscus oculoides). However, in all cases, Antarctic species occur most frequently in coastal zone sediments. Representatives of Antarctic species have adapted, it seems, to considerable fluctuations in water salinity and

[1] Usual numerical relationship between the quantitative percentages of colonial and individual species in the sediments.

37/

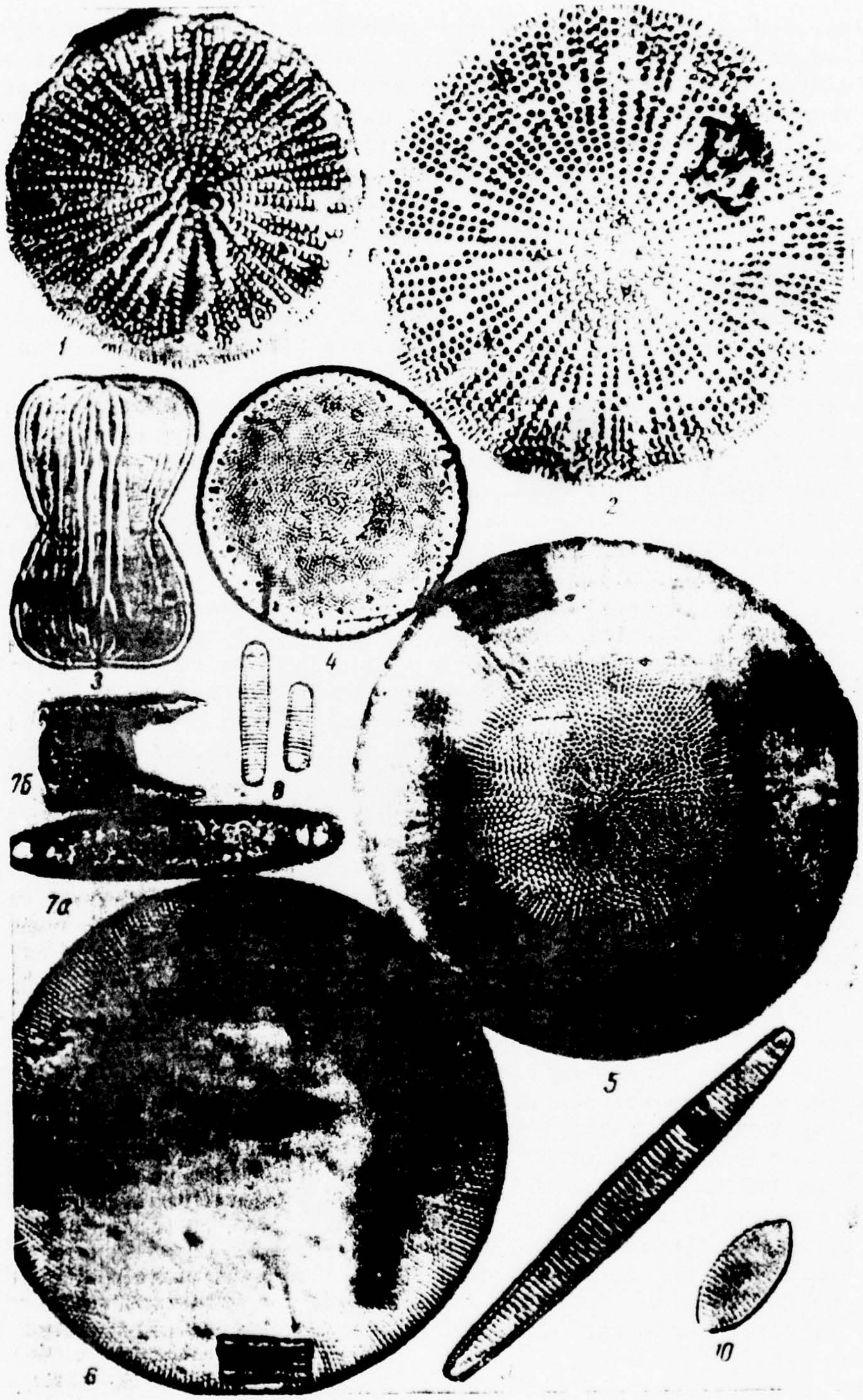

Fig. 17. The Antarctic diatom complex.

1, 2 - Charcotia actinochilus (Ehr.) Hust.; 3 - Amphiprora Kjelmanii Cl.; 4 - Porosira pseudodenticulata (Hust.) Jouse; 5, 6 - Coscinodiscus bouvet Karsten; 7 - Eucampia balaustium Castr.: a-with collar, b-with valve, 8 - Fragilariopsis curta Hust.; 9 - Fr. sublinearis Heiden et Kolbe; 10 - Fr. rhombica Hust.

temperature, i.e., to variation of the principal factors regulating the distribution of diatoms. The dates of growth of Antarctic species are closely related to the dates of sea ice break up. Masses of vegetation begin to grow while still under the ice, as soon as the snow cover melts. Masses of diatoms are seen near the ice edge. The movement of the zone of rapid Antarctic diatom growth into open ocean regions depends on the width of the ice belt (fringe ice). The direct influence of the ocean ice regime on the biology and distribution of these diatoms makes it possible to label neritic species of the Antarctic zone as glacial. Their analog are the Arctic and Arctic-boreal neritic species, which form the most cold-loving contemporary diatom flora of the northern hemisphere. In Antarctic waters, during the period of mass plankton growth, the water temperature ranges from -1.7 to -1.9°C.

The Antarctic diatom complex has been found in sediments at 7 stations on the shelf near shore (175°-150°E), where their content reaches a maximum of 97%. At some stations this drops to 64%, due to sublittoral diatoms. The ranges of Fragilariopsis curta and Eucampia balaustium are shown in figs. 7 and 9. Both species are colonial types; Fr. curta is remarkable for the mass quantities in which it is found in shelf sediments. Its maximum content is 68% (st. 373), the minimal - 12%. In sediments at station 371, Fr. curta accounts for 25.2 million valves out of the total of 64 million valves/g. In the diatom oozes, the Fr. curta content drops to several tenths of a percent. Eucampia balaustium - a large form which is typical of the Antarctic complex, comprises a maximum of 38%. Only thick-walled silicized winter valves are preserved in the sediments, while thin-walled summer valves dissolve in the overlying waters.

38/

Diatom Algae of Tertiary Age on the Surface of the Pacific Ocean Bottom

In studying diatoms in the surface sediment layer of the Pacific Ocean, numerous facts that reveal the presence among them of species of Tertiary age were uncovered. Admixture of Tertiary forms turned out to be quite typical of contemporary Pacific Ocean sediments, although this phenomenon is of considerably smaller scale than in the Okhotsk and Bering seas (Zhuze, 1954a). Tertiary diatom elements can be found in sediments from the northern to the southern margins of the ocean, but their number varies. However, only in relatively rare cases are proven outcroppings of Tertiary sediments found on the surface of the bottom. In an overwhelming majority of cases, the Tertiary diatom forms, as well as silicoflagellates and radiolaria, occur in the surface sediments through secondary deposition. The main features indicating redeposition are the extreme sparcity and homogeneity of species composition of the older forms of the coarser siliceous skeletal species that can survive redeposition. Tertiary forms usually occur as individual specimens, frequently as fragments with clear marks of corrosion on the shells. Tertiary diatoms can occur in large numbers as a result of Tertiary sediments sliding down the slopes of elevations, but they are just as poorly preserved.

Based on all existing data, one can distinguish three groups of factors. The first group consists of rare cases where Tertiary diatoms and other siliceous organisms occur in the sediments in the primary bedding (initial deposition). Consequently, Tertiary sediments are exposed on the surface of the bottom. The second group consists of numerous cases where Tertiary forms

occur in the surface sediment layer with no admixture of contemporary diatoms. At the same time, in most cases, the older forms occur as individual specimens, most often represented by fragments that are practically unidentifiable. The most characteristic feature of such finds is their confinement to the deep-water red clay region north and south of the diatom-radiolarian and carbonate sediment belt of the ocean's equatorial zone. Typical red clays in the tropical regions of the ocean are practically devoid of contemporary diatom remains, because they are located in almost lifeless waters.

The third group consists of the most frequent cases of occurrence of Tertiary forms simultaneously with contemporary or Quaternary diatoms. In these cases, the admixture of Tertiary species is insignificant and they are equally imperfectly preserved. In diatom sediments in the northern part of the ocean, in the equatorial zone, and in Antarctic regions, individual Tertiary elements disappear in the enormous mass of contemporary species corresponding to the age of the sediments.

Thus, Tertiary diatoms are found frequently in the surface sediment layer of the Pacific Ocean, and in most cases there is no question that they have been redeposited. All these facts testify to the introduction of ancient diatoms, as well as radiolarians and other organisms, into contemporary sediments. Marine diatomites of Tertiary age are widespread along many coasts of the Pacific Ocean. They can serve as the source of the influx of ancient forms into the sediments (Zhuze, 1968b). In the central parts of the ocean, far from the coast, the source of ancient diatoms in contemporary sediments must be outcrops of Tertiary rocks on the bottom of the ocean. As was established, such outcroppings exist and they are not rare. One of the most reliably identified areas of Tertiary sediments appears at station 5074, where
39/ a 300 cm core was taken during the 34th cruise of the VITYAZ'.

Station 5074 (10°30'7"N, 140°01'W) is situated on a 300 m high rise. In the upper sediment layer of the core were a very large number of well preserved Tertiary diatoms and radiolaria and a number of individual Tertiary silicoflagellates (Naviculopsis biapiculata Lemm. - now an extinct form). At the same time, ancient remnants are found with no admixture of contemporary Pacific forms. One gram of dry sediment contained 2 million Tertiary diatoms and 53,000 radiolaria. The diatom flora was represented by the following Tertiary species: Asterolampra marylandica Ehr., Cestodiscus pulchellus var. maculatus Kolbe, Coscinodiscus lanceolatus Castr., C. paleaceus (Grun.) Ratt., C. vigilans A. Schmidt, C. lewisianus Grev., C. aeginensis A. Schm., and C. marginatus Ehr. forma fossilis Jouse, which are typical of Late Miocene flora. In addition, there are also many fragments of large Coscinodiscus valves (undifferentiated by species). Coscinodiscus marginatus Ehr. forma fossilis Jouse (Jouse, 1961) predominates quantitatively among the ancient species. Among contemporary Pacific Ocean flora, Coscinodiscus marginatus Ehr. is the most typical oceanic northern-boreal species. South of 40°N this species is rarely found in diatom complexes. Consequently, the Tertiary range of this species was considerably wider than the contemporary one. Coscinodiscus marginatus Ehr. forma fossilis is the most common species among diatomites of Miocene-Pliocene age along the northwest and northeast coasts of the Pacific Ocean. With the cooling of Quaternary times, the range of this species has shrunk and is presently confined to the cold regions of the Pacific Ocean. Coscinodiscus marginatus Ehr. forma fossilis Jouse has been found in abundance in Miocene sediments exposed by the drilling of the "Mohole" 40 miles east of the southeastern end of Guadelupe Is. (28°58'N, 117°28'W). Dr. Riedel, the geologist director of the "Mohole" project, provided three samples for diatom study (W. B. Riedel et al., 1961).

In sediments at station 5153 (1°N, 160°E; depth 4,220 m), one can also assume the presence of primary bedding (initial deposition) of Tertiary diatoms, even though their overall state of preservation is considerably worse than at station 5074. Station 5153 is in the carbonate ooze region. Near this station, carbonate sediments are very poor in diatoms belonging to comtemporary floral complexes. Station 5153 sediments contained 1.7 million valves of Neogene diatoms and 32,000 radiolaria per gram. Near station 5153, bottom relief is such that it is difficult to assume that Tertiary sediments there were redeposited from the slopes of elevations. However, some doubt about the primary bedding of the Tertiary sediments remains. The very poor state of preservation of almost all Tertiary forms makes one consider the mechanical damage to the thin shell of the diatoms. Overall, the species composition of diatom flora at this station is younger than at station 5074. Coscinodiscus marginatus Ehr. forma fossilis, not mentioned by Kolbe (1954) among the diatoms in sediments at the ALBATROSS station 76 (at a depth of 5.5 m from the top of the core)[1], was absent. In addition Thalassionema nitzschioides var. parva Heiden, a species still living at the present time also occurred there. Fragments of Tertiary Coscinodiscus and Auladiscus species occurred in abundance at station 5153.

According to Riedel's data (Riedel, Funnel, 1964), Eocene sediments lie at station MSN-153 (near station 5074), 64 cm below the surface of the bottom, while at station MSN-146 (southwest of station 5074), Pliocene sediments lie 28 cm below the surface. Consequently, in this region, probably
40/ due to extensive dissection of the relief, deposition of Quaternary and, to a considerable degree, also Tertiary sediments occur in a number of places.

Even less reliable (in comparison to stn. 5153) is the primary bedding state of Tertiary diatoms and radiolaria on station 3869. This station lies east of the Marshall Islands (0°17'8"N, 173°30'6"E; depth 5,241m) and, based on its relief, ancient sediments can have slid down the slopes of elevations. The extremely poor preservation of ancient diatoms and radiolaria in the sediments of station 3869 indicates that these remains were redeposited. According to S. B. Kruglikova's data, the quantity of radiolaria there is approximately 123,000 spec./g, while the quantity of diatoms is 0.37 million valves/g. These figures are quite approximate, because all radiolaria and diatoms are represented by small fragments in the sediments.

At some stations in Drake Strait, Tertiary diatoms occur in mass quantities. One can assume, that Paleogene diatomaceous rocks are being eroded in that region. Stephanopyxis, Triceratium, and Trinacria, characteristic representatives of Eocene flora, predominate among the diatoms. There is a noticeable similarity to Late Eocene flora known to exist near Oamaru on the Pacific coast of South Island, New Zealand. Sediment samples from stations DWBG 23B, MSN-5G, and MP 5-1, containing Tertiary radiolaria and foraminifera received from Dr. W. Riedel of Scripps Institution of Oceanography, also contain large quantities of Tertiary diatoms (Zhuze, 1968b).

A preliminary inspection of the sediment samples collected by American expeditions indicates an Eocene-Oligocene diatom complex in the sediments at stations DWBG 23B, MP-I, and MSN-5G. Representatives of Paleogene flora: Triceratium, Hemiaulus, Kittenia. Auliscus, and Riedelia, predominate among the diatoms.

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[1] At the present time, the age of station 76 sediments situated 5.5 m below the ocean bottom surface is estimated to be Miocene.

Encounters with Tertiary diatoms that comprise the second group are confined to the deep-water red clay region. They occur north of 15°-10°N and south of 5°S. In all cases, the Tertiary diatoms are very poorly preserved, are fragmentary, and can not be separated by species. They are remarkably homogeneous in composition. Fragments of large Coscinodiscus, Aulacodiscus, Hemiaulus, Triceratium, and Riedelia, species known for their coarse siliceous valves usually are present.

In deep-water red clays of the tropical region, Tertiary diatoms are not masked by contemporary forms, as occurs in diatom oozes in the northern ocean, in the equatorial zone, and in Antarctic regions, but their layering is not primary. Most finds of Tertiary shark teeth, which should be regarded as eroded from ancient deposits exposed on the slopes of underwater hills, also occur in the same latitudes (Belyayev, Glikman, 1965). This is shown by the fact that most Tertiary shark teeth were found in trawl samples and only relatively few teeth occurred in bottom dredge samples.

In the equatorial belt of diatom-radiolarian oozes, Tertiary species occur in the same numbers, but are lost there among the large mass of contemporary forms. No special features are seen in the species composition; they are the same species as in deep-water red clays, and are equally well preserved. From such a concurrence (of Tertiary and contemporary species), the secondary origin (redeposition) of Tertiary elements is especially obvious, which also applies to ancient elements in Antarctic diatom sediments.

41/ It would be hard to explain the presence of early forms in the Pacific Ocean surface sediment layer, if there were no cases where Tertiary deposits lie directly on the surface of the bottom. A number of opinions on this question occur in the literature. Riedel (1952) was first to notice the intermixture of contemporary and authentic, extinct Tertiary radiolaria in Pacific Ocean surface sediments. Analyzing the possible causes of occurrence of Pre-Quaternary forms in recent sediments, Riedel assigns the main role to the erosion of rocks, outcrops of which are quite frequent on elevations of the bottom and in deep depressions. Existing data on this question have been summarized by Riedel and Funnel (1964). Of 900 cores collected by American expeditions, 85 were analyzed. In these cores, Tertiary sediments appear at, or very close to the surface of the bottom. The age of the sediments was determined from radiolaria, foraminifera, and coccoliths. In total, Riedel mentions approximately 30 places with authentic outcrops of Tertiary sediments lying on or near the surface of the bottom. If one observes how these outcrops are distributed on the ocean bottom, one is convinced that they are confined to sediment regions north and south of the equatorial belt of organogenic ooze. No outcrops of Tertiary sediments have been found in the equatorial zone. At stations MSN-12 and Cap. 2B, Pliocene sediments are covered, according to Riedel, by a 120-150 cm thick layer of Quaternary deposits.

At ALBATROSS station 76, Pliocene sediments lie even deeper. Kolbe (1954) thought that the Pliocene-Pleistocene boundary in this core lay 5.5 m from the surface of the bottom. The lower parts of 3 m long cores studied at station 3797 (Zhuze, 1963) and station 3802 (Mukhina, 1963) correspond to the Middle and Early Pleistocene. Even longer cores at ALBATROSS stations 62 and 58, taken very close to the equator, revealed 8 to 14m thicknesses of Quaternary sediments (Riedel, Bramlette, Parker, 1963).

Therefore, it is hard to assume that in the equatorial zone east of 180°W, Tertiary sediments crop out on the surface of the ocean bottom, except on elevations. Outcrops of Tertiary sediments are confined, according to Riedel and Funnel (1964), to the zones north and south of and directly adjoining the equatorial zone.

From the above it follows that during Tertiary times, the productive equatorial zone was wider than the contemporary one and, consequently, outcrops of Tertiary sediments occur most frequently near contemporary boundaries of equatorial organogenic sediments. Studying locations of Tertiary sediments on the bottom, Riedel concluded that in the Eocene-Pliocene, the equatorial current system covered a wider zone of the ocean than in the present period. Apparently, the productive equatorial zone did not remain constant in width during Quaternary times. In cool epochs, the equatorial productive zone became almost 5° narrower due to the incursion of cold waters from the north and south. In the same period, the southern boundary of the equatorial zone moved northward not more than 2-3°.

Therefore, one should be very cautious in deciding in which type of bedding (primary or secondary) the ancient elements occur. The data studied on diatom distribution in surface sediments indicated that redeposition occurs in most cases. One should be cautioned against the temptation to see Tertiary sediments everywhere there are individual remains of Tertiary organisms, especially if they are mixed with contemporary forms.

42/

Silico-flagellates (Siliceous Flagellate Algae) in the Surface Layer of Bottom Sediments

Silicoflagellates, common associates of diatom algae, appear in significantly smaller quantities in sediments. The content of Silicoflagellates, even in sediments richest with them, is several of tens of times smaller than that of diatoms. The difference in species composition is just as great. It is doubtful that there are more than ten silicoflagellate species in contemporary seas and oceans. The diversity of silicoflagellates is enhanced by the presence of numerous varieties and ecological forms. Silicoflagellates are typical marine organisms on the border line between the plant and animal kingdoms.

To continue the analogy between diatoms preserved in sediments in the form of outer shells and silicoflagellates, which are preserved in skeletal form, one should mention that the evolutionary development of both groups has much in common. The earliest occurrences of silicoflagellates are assigned to the late Mesozoic; species of Cretaceous age are completely extinct; typical Cretaceous genera did not survive into the Paleogene. Fossil silicoflagellates have been studied better taxonomically than contemporary ones. At the same time, knowledge of early forms is one sided; principal attention was devoted to the taxonomy of this group of algae (Deflandre, 1950; Glezer, 1964). Interest in silicoflagellates sprang up as soon as their great value in paleontological study was discovered. As a result, studies of silicoflagellates in deposits of different geological age paralleled studies of diatoms. Studies of silicoflagellates in Tertiary and Quaternary bottom sediments lag significantly in this respect.

Existing uncoordinated data do not give a complete picture of silicoflagellate distribution in contemporary sediments of the seas and oceans. New data from the study of 200 sediment samples from the Pacific Ocean somewhat reduce this deficiency. Comparative data on the quantitative distribution of diatoms and silicoflagellates are quite representative. If the typical concentration of diatoms in the sediments is several tens of millions of

tests per gram (or even several hundred million, as in Antarctic diatom oozes), for silicoflagellates it drops to several tenths or even hundredths of a million and, more rarely, to 1-4 million tests/g. Consequently, microscopic skeletons of silicoflagellates, which are close in size to those of diatoms, can not be a source of deposits of large amounts of amorphous silica.

Therefore, the small population of silicoflagellates determines their limited role in the silica accumulation process in contemporary oceans. There are no cases where silicoflagellates determine sediment type, as diatoms and radiolaria do (the former by means of mass concentrations, the latter because of the large size of their siliceous skeletons).

Because silicoflagellate skeletons are well preserved in sediments, the bottom is a sufficiently accurate reflection of the distribution of these organisms in the active layer of the ocean. Unlike sediment diatom complexes, which differ from their coenoses, silicoflagellate complexes apparently, retain quantitative correlations between the species of their coenoses, it seems. This makes it easier to use silicoflagellates in marine micropaleontological studies. The proportion of silicoflagellates in phytoplankton of the Pacific Ocean is not great, as can be deduced from voluminous data. Silicoflagellates comprise only a few tenths of one percent of the total phytoplankton. In samples of suspended matter from
43/ the surface layer of the ocean, silicoflagellates comprise only several tenths or hundredths of a percent of the total quantity of siliceous algae.

In the surface sediment layer of the Pacific Ocean, one can identify three regions with relatively high silicoflagellate content (fig. 18). The first lies south of 45°N in the northwest part of the ocean, in the Gulf of Alaska and near the North American coast, it rises to about 55°N. The second region is as rich in silicoflagellate remains and is confined to the equatorial belt, extending from 180° to 140°W where it widens considerably. The third region is south of 55°S.

44/ In the Northwest Pacific, the maximum density of silicoflagellate specimens is estimated to be 3.34 million spcm/g. A long, rich strip of silicoflagellates stretches east of Japan to approximately 170°E. Outside it, the number of tests drops below 1 million tests/g. North of 45°N, silicoflagellates are practically absent in sediments of the western part of the ocean. Only at station 3252 were there 0.08 million tests/g. A typical zone of sediments with a large content of silicoflagellates is almost 20° wide, from north to south, on the northeast margin of the ocean. The number of cells does not exceed 1 million spcm/g. Warmer waters in the northeastern regions favor the growth of warmth-loving silicoflagellates. Cold subarctic waters inhibit the growth of most species, which explains their absence in sediments north of 45°N. At many stations in this region, there were no fewer than 18-20 million valves/g and silicoflagellates were completely absent.

Among contemporary representatives of this group of algae, only Distephanus speculum is unquestionably a cold-loving species. It is known in coastal plankton of the Bering and Okhotsk Seas and occurs more rarely in plankton in the northern parts of the ocean. The main area of growth of Distephanus speculum is in the Antarctic regions (fig. 19), where the long-shelled variety with very rough skeleton grows. In high latitude regions (subarctic and antarctic waters), D. speculum develops long horns. Water temperatures close to 0° and even negative ones favor its growth. All other species discussed, most of which belong to the genus Dictyocha, are warmth-loving, and cannot survive in subarctic and

43/

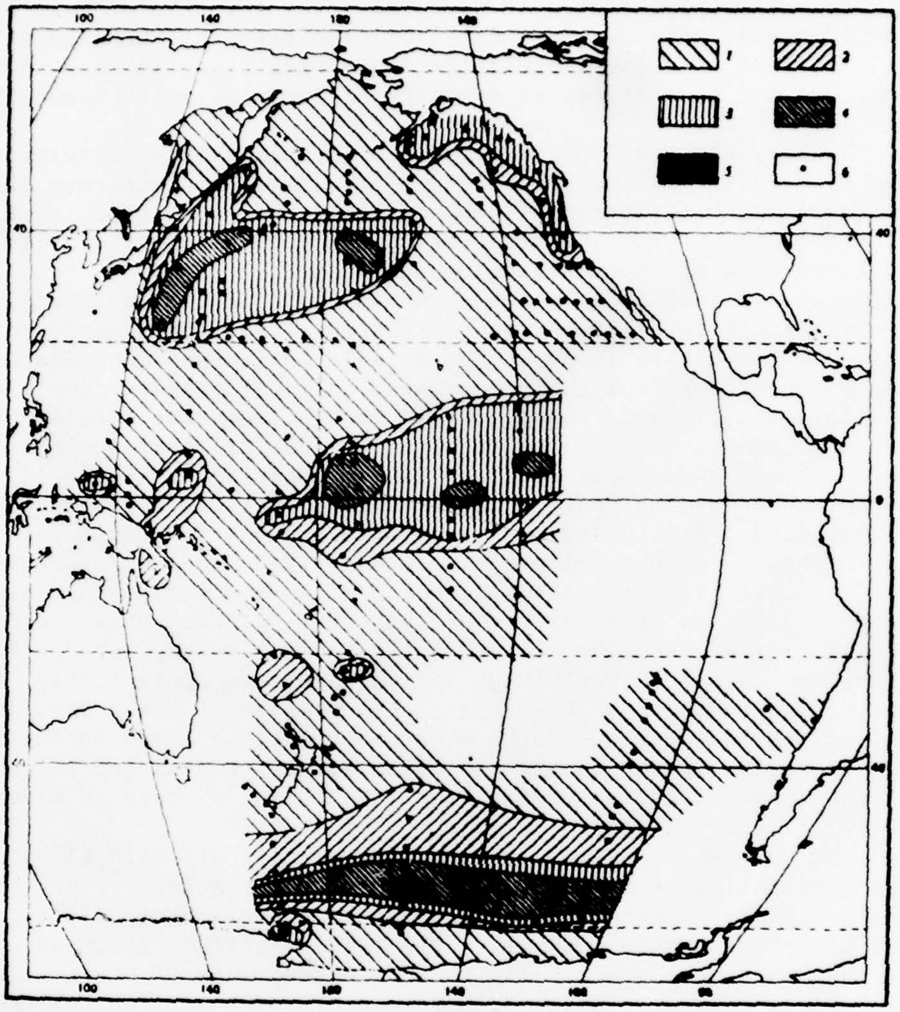

Fig. 18. Quantitative distribution of silicoflagellates in the surface sediment layer (in million specimens/g of sediments)

1) - silicoflagellates not found; 2) - 0.01-0.1 specimens/g; 3) - 0.1-1; 4) - 1-4; 5) - >4; 6) - stations studied.

44/ antarctic waters. It is thought that the 18°-20° isotherm limits the growth of most forms of the genus Dictyocha (Gemeinhard, 1930). There probably are different ecological races among Distephanus speculum, as among Dictyocha fibula--the most wide-spread species of contemporary Dictyocha.

The chart of quantitative distribution of silicoflagellates in surface sediments shows the warmth-loving nature of most of their species. Equatorial sediments contain a maximum of 2.0 million silicoflagellate tests/g, but usually their concentration is closer to 1 million tests/g.

45/

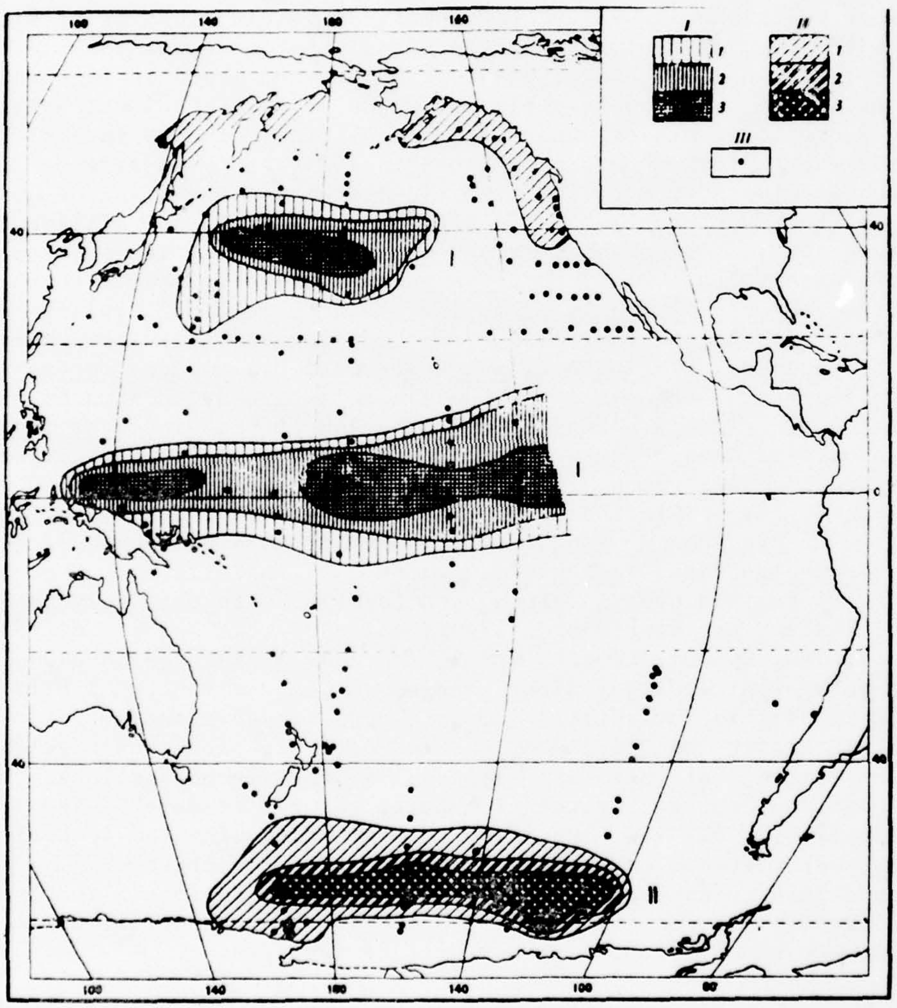

Fig. 19. Distribution of silicoflagellates in the surface sediment layer (in mill. specimens/g).

I - Dictyocha fibula Lem. (complex of forms): 1) - 0.01-0.1 mill spcm/g; 2) - 0.1-1; 3) - >1; II - Distephanus speculum Ehr.; 1) - 0.01-0.1; 2) - 0.1-1; 3) - >1; III - stations studied.

44/ Regions rich in silicoflagellates, diatoms, and radiolaria coincide in the equatorial belt. Extensive ocean bottom areas between 5°-7° and 50°S are practically devoid of silicoflagellate remains. They are completely absent in carbonate oozes in the eastern part of the ocean, between 110°-100°W. Small quantities occur north of New Zealand, between 25°-30°S.

South of 50°S, silicoflagellates appear again--in small quantities at first. The silicoflagellate content increases sharply in the diatom ooze zone between 55° and 65°S. At station 386 there were 5.5 million tests/g--more than at any other station. The greatest quantity of diatoms so far recorded in Pacific Ocean sediments, 441 million valves/g, was at the same station. In terrigenous and icerafted sediments, silicoflagellates never exceed several hundred thousand tests/g.

A direct relationship between the quantitative distribution of silicoflagellates and type of sediments can be seen. Diatom and diatom-radiolarian oozes are richest in silicoflagellates. They are not found in deep-water red clays and heavily carbonate sediments. The shape of sediment areas
45/ containing deposits of diatoms and silicoflagellates coincide in most regions. However, the warmth-loving nature of the principal groups of silico-flagellate plankton requires warm water. In Antarctic diatom oozes and in the north-west, only Distephanus speculum has a high content--up to 3-4 million tests/g.

Only one species, Distephanus speculum Ehr., actually grows in subarctic and Antarctic latitudes. Dictyocha fibula Lemm. are very rarely found. The complex form of Dictyocha fibula predominates in the silicoflagellate complex south of 40°N. Its volume increases toward equatorial latitudes, where the D. fibula f. rhombica, D. fibula f. acunumata, and Distephanus octonarius variant types appear. The ranges of these species are delineated by the
46/ 18°-20° isotherm. Fig. 19 shows the distribution of the Dictyocha fibula complex. As can be seen, the two regions of high frequency of occurrence of this silicoflagellate group in the Pacific Ocean are: south of 40°N in the subtropical zone and in the equatorial belt between 5°N and 5°S. The range centers of Distephanus speculum are north of 40°N and south of 55°S. Distephanus speculum forma septenarius (which has fine siliceous skeleton and seven short protrusions) is often seen together with the Dictyocha form complex. The shape and degree of silicification of this species differ in Antarctic regions, Sea of Okhotsk, and Bering Sea. This case is a good example of polymorphic-morphological changes due to environmental differences.

This well defined variability due to changes in environment, wide distribution, relative simplicity of species determination, and significant presence in sediments are all features peculiar to silicoflagellates that make them highly useful for marine micropaleontologic research. The study of silicoflagellates also is simplified in that it requires no special samples, but use the same samples as studied for diatom algae.

Only the main features of silicoflagellate distribution in the ocean surface sediment layer were presented above. Future more detailed study of the taxonomy and ecology of this group will be required.

Conclusions

1. A study of diatoms and silicoflagellates in the surface sediments was made to determine the stratigraphic and the paleogeographic conditions for sedimentation in the Pacific Ocean. The quantitative content and species composition of diatoms and silicoflagellates in contemporary sediments are the primary data that help us understand the geological past.

2. The quantitative distribution of diatoms on the bottom is quite uneven. In some regions, diatoms form a significant part of the sediments, while in others they are practically absent. The highest diatom content, 450 million valves/g, typifies diatom muds of the Antarctic. In diatom oozes of the Okhotsk and Bering seas, the diatom content is two-three times smaller. Near the northwest and northeast margins of the ocean, the diatom content of sediments decreases on the average to 30-35 million valves/g. Very similar concentrations of diatoms (maximum of 35 million valves/g) characterize sediments of the equatorial zone. Deep-water red clays and partly carbonate oozes of tropical regions are devoid of diatom remnants. However, in a number of cases, carbonate oozes have diatom contents of 15-20 million valves/g.

3. The quantitative distribution of diatoms in sediments depends primarily on their quantity in the plankton of a given region. Subsequent factors, such as decomposition rate, degree of terrigenous and organic dilution, and fossilization conditions, determine the concentration of diatoms in bottom sediments.

4. The species composition of diatom flora in sediments repeatedly changes from the northern to the southern borders of the ocean. Species composition is determined, primarily by surface water temperature and distance from the coast. Individual peculiarities of neritic and oceanic
47/ diatom complexes are well defined in sediments. Flora of a particular species composition are typical of different climatic (geographic) zones and their respective water masses.

5. The following seven main species complexes succeed each other consecutively from north to south in the surface sediment layer: Arctic-boreal, northern-boreal, subtropical, tropical, equatorial, subantarctic, and Antarctic.

Each complex or thanatocoenosis contains co-existent species, whose range centers and quantitative maxima are confined to the sediments of their respective zones. Content of the species that determines the nature of the complex is a maximum of 90-98%. Elements of the two adjacent complexes merge in transitional regions at borders between zones. The composition of the independent complexes, excluding the least studied subtropical diatom complex, contain many endemic species.

6. Among the sediment diatom complexes listed, the subtropical complex has been studied least, and its true independence is contested by some scientists. However, it is incorrect to call this complex mixed, i.e., one containing north-boreal as well as tropical elements. In addition to north-boreal and tropical species, it also contains a large group of temperate warmth-loving species with their range centers and quantitative maxima in northern subtropical waters. Definition of the subtropical diatom complex is especially important for paleogeographic reconstruction. During warm epochs, regions of subtropical diatom growth were shifted northward and not tropical ones.

7. The scarcity of groups of silicoflagellate algae, or silicoflagellates, is a good indicator of past sedimentation temperatures. Silicoflagellates are a mainly warmth-loving group of planktonic organisms. The only contemporary cold-loving species is Distephanus speculum Ehr. The quantitative content of silicoflagellates in sediments is several tens and even hundreds of times smaller than that of diatoms. Further ecological studies of the discussed group of algae will permit their wider use in reconstruction of paleoclimates.

8. Sediments of Tertiary age have been found on the surface of the ocean bottom at several stations; this was confirmed by the presence in sediments of Tertiary diatoms, silicoflagellates, and radiolaria in primary layers (first deposition). Redeposited Tertiary diatoms are distributed much more widely in sediments, which indicates the profusion of outcrops of Tertiary sediments on the bottom of the Pacific Ocean. The redeposited Tertiary diatoms are poorly preserved, have a sorted species composition (consisting exclusively of skeletons of species), and bear traces of repeated redeposition.

48/

Chapter II

Radiolaria in the Surface Sediment Layer of the North Pacific Ocean

S. B. Kruglikova

INTRODUCTION

Radiolaria are single-celled, solely marine, pelagic organisms inhabiting the entire ocean water column, from the surface to abyssal depths. Radiolaria range in size from several tenths of a micron to several millimeters; deep phaeodarians-to more than 10 mm. Colonial forms, with colonies reaching several centimeters in size, are found.

The subclass Radiolaria (class Sarcodina) consists of 5 orders-Acantharia, Spumellaria, Nasselaria, Phaeodaria, and Sticholoncha (Dogel', 1951); only two of which, Spumellaria and Nassellaria, have siliceous skeletons and are well preserved in bottom sediments. Representatives of a third order, Phaeodaria, are very rarely found in contemporary sediments, but no authentic data on the presence of radiolaria in ancient deposits exist at present.

Two orders of radiolaria, Sticholoncha and Acantharia, are not preserved in bottom sediments, even though Shevyakov (1926) has found up to 21.6% of SiO_2 in the composition of complex aluminum-calcium silicate in skeletons of acantharians. Consequently, the preservation rate of radiolaria in bottom sediments depends first of all on the chemical composition of their skeletons.

Skeletons of radiolarians in the various zoogeographic regions of the ocean possess a number of specific morphologic features. In warm waters, radiolaria like other planktonic organisms, have more highly developed buoyancy organs. The thinnest and smallest skeletons and, correspondingly, the lowest weight per volume are typical of warm-water radiolaria. Their skeletons have well developed burrs, needles, and radial branches.

Larger, thick-walled forms with fewer needles and poorly developed branches are more widespread in cold waters. Almost smooth forms often are found. Habitation at great depths leads not only to adaptation to lower temperatures, but also to development of features that increase skeletal strength and protect the cytoplasm from the high pressure. Thick-walled, finely porous skeletons are distinctive of deep-water radiolarians. The deep-water Phaeodaria have solid shells with tubular needles and thick, massive partitions (Khabakov, 1959).

Characteristic radiolarian complexes were formed by selection under the influence of different physicogeographic conditions in the ocean: in cold, temperate, and tropical waters; in surface water layers; and at great depths. Radiolarian fauna change significantly through time because the morphologic features of radiolarian skeletons reflected in their enormous species diversity, correspond to hydrodynamic conditions of their environment.

49/ All these features make radiolarians important in stratigraphy and in paleogeographic interpretation of sedimentation conditions (deflandre, 1953; Lipman,1952, 1959, 1960; Riedel, 1952, 1954, 1957, 1958, 1959a, b; Riedel, Bramlette, 1959).

Orders of radiolarians, whose skeletons are well preserved in marine sediments, and some other organisms (siliceous sponges, diatoms, silicoflagellates) are an important source of accumulation of organic silica in sediments. According to tentative estimates by Riedel (1959a) diatoms, radiolarians, and to a lesser extent, sponges and silicoflagellates comprise up to 40% of some pelagic oozes in the Pacific Ocean. Only the first three groups are significant in sediment formation (Lisitsyn, 1966). However, what part of the silica is contributed by radiolaria and what part by other organisms remains unclear. It is thought that radiolaria comprise approximately 20% of radiolarian oozes (Strelkov, 1959).

The present work was performed under the leadership of A. P. Zhuze in the Ocean Geology Section of the USSR Academy of Science, Institute of Oceanology. The study of the systematic composition of radiolaria in bottom sediments of North Pacific Ocean was made under the leadership of A. A. Strelkov at the Zoological Institute of the Academy of Science.

This chapter discusses a) the systematic features of the quantitative distribution of radiolaria in sediments of the surface layer of the North Pacific Ocean, b) dependence of the distribution of radiolaria on zonal factors and material types of sediments, and c) distribution of certain mass species.

History of Research

Information about radiolarian fauna of the Pacific can be found mainly in Haeckel's monograph (Haeckel, 1887). This monograph was based on data from the 1873-1876 CHALLENGER expedition. Prior to this expedition, radiolaria of the Pacific Ocean were almost unstudied. Haeckel's work describes radiolaria in plankton and in bottom deposits of the Pacific Ocean. He lists 4,318 species, 3,508 of them new.

Unfortunately, in his description of radiolaria of the Pacific Ocean, Haeckel frequently mentioned only one or a few locations of observations, sometimes without stating whether the species were found in the overlying ocean or in the bottom deposits. Haeckel's work is a priceless contribution to the development of radiolarian taxonomy, but has no great zoogeographical significance.

The work of Dogel' and Reshetnyak (1952) and Reshetnyak (1955) are devoted to radiolaria in plankton of the Pacific Ocean. The former work deals with radiolarian fauna of the Northwest Pacific near the Kamchatka coast. This work describes 85 species of radiolaria, 21 of which are new. The second work deals with the vertical distribution of radiolaria in plankton of the Kurile-Kamchatka Trench and is of considerable interest in the study of radiolarian ecology. In this work, Reshetnyak identified 104 species of <u>Phaeodaria</u>, <u>Nassellaria</u>, and <u>Spumellaria</u>. According to her data, <u>Phaeodaria</u> comprise the main mass of the radiolarian complex in waters of the Kuril-Kamchatka Trench.

Reshetnyak distinguishes two ecological categories of radiolaria: 1) stenobathic, living in strictly defined depths (42 species), and 2) euribathic, living at different depths (54 species). Reshetnyak was able to assign the stenobathic forms to definite layers or horizons of waters of the Kurile-Kamchatka Trench. She could distinguish (1) surface (0-50 m), (2) subsurface (50-200 m), (3) transitional (200-1,000 m) (4) intermediate depth (1,000-2,000 m), (5) bathypelagic (2,000-4,000 m), and (6) abyssal (4,000-8,000 m) species.

According to Reshetnyak's data, euribathic radiolaria have different degrees of euribathicity. She distinguishes two groups of species, one of which is found almost throughout the water column, from 200 to 8,000 m (28 species); the second group's distribution is limited to the 200 to 2,000 m zone (26 species). Quantitative data on the distribution of radiolaria are absent in Reshetnyak's work. The radiolarians have been studied very inadequately in the deposits of the Pacific Ocean.

In 1856 Bailey (1856) published information on microflora and microfauna, in sediments taken from the Kamchatka region. His work describes 13 species of radiolaria.

A very small amount of data on radiolaria of the northwest part of the Pacific Ocean is found in T. J. Gorshkova's work (1952). Based on study of a 92-cm-long core obtained near the southern end of Kamchatka, Gorshkova lists radiolaria (only 18 names) and data on the relative abundance of each species (number of specimens visible) in four levels in the core.

Data on radiolaria in bottom deposits of the Pacific can be found mainly in Riedel's works. His 1952-1957 work on radiolaria in sediments of western tropical region of the ocean were based on data of the 1947-1948 Swedish deep-water expedition of the ALBATROSS. Studying deposits of the tropical part of the Pacific in order to clarify their stratigraphy, Riedel had to select index species to determine the age of the sediments. He established that certain species of radiolaria have wide geographic distribution and sufficiently short time limits; very frequently their existence is confined to a single epoch of the Tertiary period. Above all, Riedel found that many species are common to deposits of Tertiary age on both continents and in bottom deposits of the Pacific Ocean. On the basis of studies of the faunal composition of radiolaria, Riedel pointed out the presence of outcrops of Tertiary deposits exposed on the surface of the bottom in several regions of the Pacific Ocean.

Riedel (1957) identified several species having more or less established time boundaries, and assumed them to be suitable to determine the approximate age of tropical Pacific sediments. In his dating, Riedel used such terms as "Early," "Middle," and "Late" Tertiary age. Later, he wrote about the possibility of more exact age determination of sediments (Riedel, 1959b). Riedel studied sediments collected in the Pacific Ocean by expeditions of the Scripps Institution and came to the conclusion that radiolaria, at least in the tropical region of the ocean, are suitable for stratigraphic correlation of Oligocene and Lower Miocene sediment sections located considerable distances from each other.

The joint work by Riedel and Funnell (1964) presents, based on studies of radiolarian and planktonic foraminifera, a detailed stratigraphic section of sediments in 85 cores from the Pacific Ocean. The age of the sediments was from Lower Eocene to the present. Riedel gives a list of index radiolaria (43 species), frequently emphasizing that mistakes are possible when one uses radiolarian fauna for age determination of sediments. First of all, mistakes can occur in cases of mass redeposition of Tertiary radiolarians in contemporary sediments (Riedel, 1952, 1954, 1957). Secondly, Early Tertiary species of radiolaria have thicker walled skeletons than Late Tertiary and Quaternary
51/ species. Because thin-walled Late Tertiary and Quaternary forms dissolve more easily, frequently only Early Tertiary forms are found, which do not serve as indicators of Tertiary age of sediment accumulation in such cases (Riedel, 1957; Riedel, Bramlette, 1959; Riedel, Funnel, 1964).

One can form an opinion about recent radiolarian fauna of bottom deposits, based on Riedel's (1952) and Petrushevskaya's (1966) works on Antarctic radiolaria. These authors present data on the frequency that certain species are found in deposits of the Pacific Ocean.

Materials and Research Methods

Radiolarians were studied in 176 samples of the surface sediment layer of the North Pacific Ocean. 173 of these samples were collected on cruises of the VITYAZ' and 3 samples were obtained from the Scripps Institution of Oceanography (USA). The following method was used to count radiolaria in the bottom sediments. Usually the number of radiolaria was determined in 50 mg of dry sediment, but for 32 stations larger sediment portions (100, 200 mg, and more) were used. The pelite (silt, clay) fraction contaning no radiolaria was washed out of the sample. The remaining sediment containing radiolaria was placed in Canada balsam. Usually radiolaria were counted in each sediment sample, but only 1/3 or 1/4 of the total was counted when their concentrations were high. The number of radiolaria in a given weighed portion was used to calculate their quantity per 1g of dry sediment.

Quantitative Distribution

Known biological and palentologic studies of readiolaria contain no actual data on the quantitative growth of radiolaria in plankton and their concentration in sediments. In this case we are discussing primarily the the representatives of two orders of radiolaria, Spumellaria and Nassellaria, that survive in the bottom sediments. For the Pacific Ocean, Riedel (1951) mentions only one figure of 540,000 radiolarian specimens in sediments of the equatorial zone (0°20'N, 150°36'W; depth 4403 m).

The content of radiolaria in Pacific Ocean sediments can be deduced indirectly from a previously cited work by Riedel (1959a) as well as from Bandy's work (1961). Riedel studied the remains of siliceous organisms in the Pacific surface sediment layer in a region bounded by the coordinates: 180°-110°W, 60°N-20°S. Siliceous remains in the cited region are represented by diatoms, radiolarians, and partly by sponge spicules. South of 13°N to 5°-15°S are radiolarian and foraminiferal oozes in which the content by weight of organic silica (in non-calcareous material) ranges from 5 to 80%. According to Riedel, the radiolarian fauna is especially rich in the equatorial region.

Bandy's data pertains to sediments of the Gulf of California. The author determined the number of diatom-foraminifer-radiolarian complex specimens in one gram of dry sediments. According to his estimates, radiolaria comprised up to 50% of the complex in the deepest sectors of the southern part of the gulf and around certain depressions in its central part.

Nayudu and Enbyck's (1964) data on the proportion of radiolaria in sediments of different types unfortunately could not be fully used. Their article contains no data on the method used to calculate individual components
52/ of the sediments, and the data on the content of radiolaria in the sediments, presented on their charts (in percent of sediment volume), cannot be compared to our data.

The data we obtained on the qunatitative distribution of radiolaria in ocean bottom surface sediments formed the basis for compilation of a schematic chart (fig. 20). We also considered data on bottom relief and the material and genetic composition of the sediments. Radiolarians were found in 167 out of the 176 samples studied. The minimum number of radiolarians (5 spec/g) was found in deep-water red clays, while the maximum number (351,420 spec/g) was found in diatom-radiolarian oozes[1].

The quantitative distribution of radiolaria shows the influence of latitudinal zoning noticeable in the distribution of other organisms inhabiting the northern basin of the Pacific Ocean. Three zones can be seen in the sediments based on radiolarian content: boreal zone (north of 40°N), tropical zone (40°-15°N), and equatorial zone (0°-15°N).

The first zone occupies extensive areas of the North Pacific Ocean bottom. The southern boundary of the region lies at approximately 30°N in the east. Within this zone, radiolaria were found in terrigenous and weakly siliceous diatom sediments (northwest and coastal regions in the northeast); farther south radiolaria were found in deep-water red clays and foraminiferal oozes.

A radiolarian sediment content of 50,000 spec/g is most characteristic in the boreal zone, but one also finds such higher concentrations confined mainly to weakly siliceous diatom oozes of the northern silica accumulation belt (Lisitsyn, 1966). In the west of this belt, concentrations of radiolaria reach a maximum of 186,000 spec/g. Sediments with such high concentrations of radiolaria are distributed between 135° and 170°E and 35°N. In the eastern boreal zone, a concentration of radiolaria greater than 100,000 spec/g (105,800 spec/g) was found in weakly siliceous diatom oozes at one station (160°W, 41°N). Concentrations of radiolaria of 50,000-100,000 spec/g are typical for a narrow strip of sediments extending latitudinally between 40° and 50°N.

In sediments of the northern part of the Hawaiian submarine ridge, the radiolarian content decreases compared to the regions west and east of the ridge and comprises 1,000-10,000 spec/g. Even lower concentrations of radiolaria (<1,000 spec/g) are typical of the terrigenous sediments of a narrow strip along the coast of the Pacific Ocean.

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1 Below, in short, they are called radiolarian oozes.

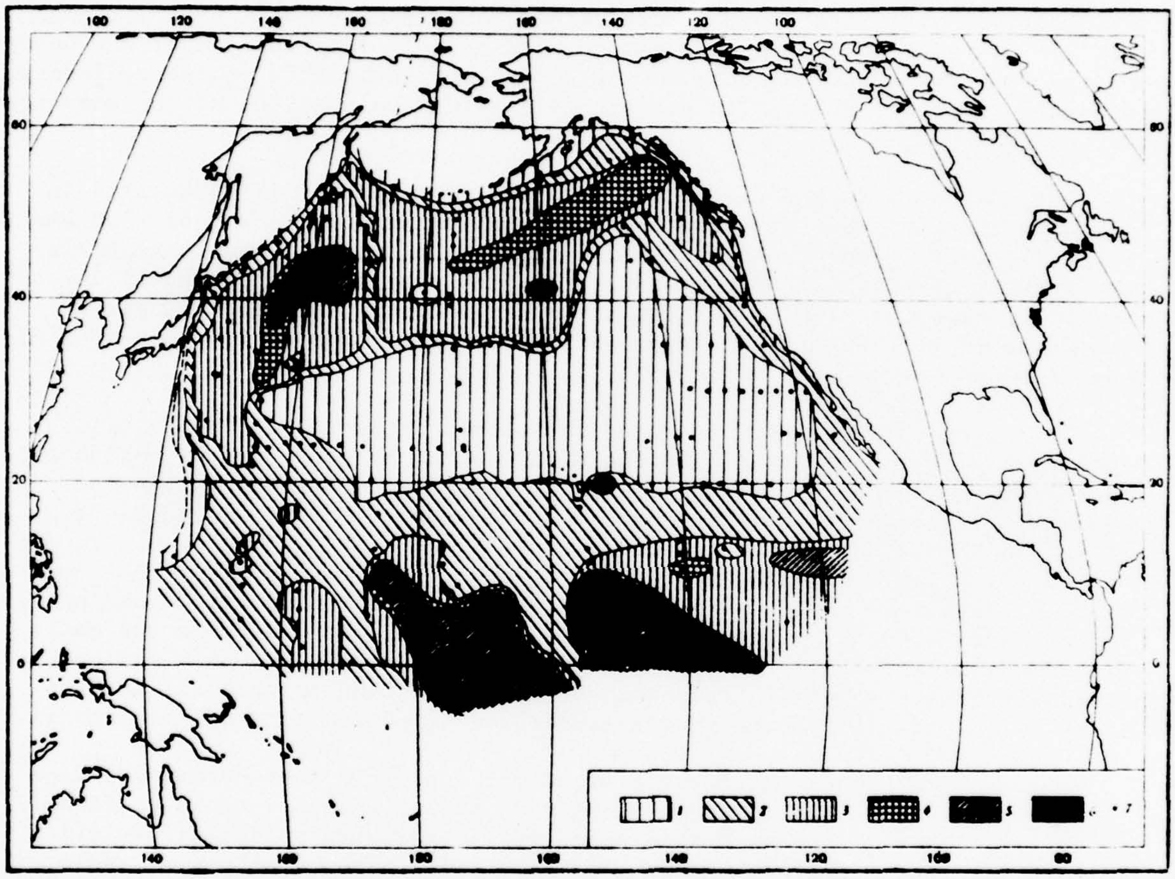


Fig. 20. Quantitative distribution of radiolarians in the surface sediment layer of the North Pacific Ocean (in thousands of spcm/g of dry sediment)

1. 1; 2. 1-10; 3. 10-50; 4. 50-100; 5. 199-200; 6. 200; 7. stations studied.

A large part of the tropical zone is occupied by red clays and foraminiferal oozes with minimum (for North Pacific) concentrations of radiolaria of 1,000 spec/g. Radiolaria were completely absent in sediments at some stations. Within tropical zone limits, the extensive region west of 170°-155°E is somewhat richer in radiolarian content (1,000-10,000 spec/g). The same concentrations of radiolaria are typical of a narrow strip of terrigenous sediments south of 45°N along the continental slope of America.

Small individual areas of sediments with "abnormally" high concentrations have been noted with in tropical zone limits. For example, near the Hawaiian Islands, the concentration of radiolaria, in places, reaches 262,000 spec/g (20°N, 152°W). An area of sediments with a concentration of radiolaria higher than 50,000 spec/g exists in the western tropical zone, along 153°-160°E.

The equatorial zone is characterized by the highest content of radiolaria in the sediments. Maximum concentrations of radiolaria that reach 350,000
54/ spec/g and, according to Riedel's data, even 540,000 spec/g (Riedel, 1951), are confined to the radiolar ian and radiolarian-foraminiferal oozes distributed in this region. It should be noted, that very high concentrations of radiolaria were found there, not only in radiolarian but also in radiolarian-foraminiferal oozes, as, for example, in the 160°-140° region. Thus, at station 5117, when recalculated on the basis of non-calcareous matter, they contain a maximum of 1,274,000 spec/g. West of 160°W, a considerable area is occupied by are also radiolarian and foraminiferal oozes. West of 140°W, the concentration of radiolaria drops to 10,000-50,000 spec/g in foraminiferal oozes and red clays.

Consequently, the distribution of radiolaria on the surface of the bottom of the northern basin of the Pacific Ocean corresponds to known general features of the distribution of phyto- and zooplankton. It seems, that as with diatoms, the picture of radiolarian distribution in plankton is quite closely reflected in sediments.

The statistical analysis, made it possible to determine the existence of a definite relationship between radiolarian content in sediments and their geographic location, depth, granulometric composition, and the material and genetic type of sediments. Average content of radiolaria represents, in all cases, the geometric mean value of their content in a series of samples, calculated according to the equation:

$$Q = \sqrt[n]{x_1 \;\; - x_2 \; ---- X_n},$$

where n is the number of samples and X_1, X_2, ----, X_n is the number of radiolaria in each sample (in 1g of sediment).

The data in table 1, compiled from information from 177 stations, confirm the assumption that sediments of different geographic zones of the Pacific Ocean clearly differ mutually in radiolarian content.

TABLE 1

Content of radiolarians in Pacific Ocean sediments in different geographic latitudes (in spec.g)

Latitude (North)	Minimum (Min.)	Median (Me.)	Maximum (Max.)	Average Content (Q)
60°-40°	20	11,125	186,840	6,810
40°-15°	5	890	262,000	660
15°-0°	60	23,280	351,540	15,200

The data shown point to the fact that sediments in the 15°N-0° zone contain, according to the direct calculations, the greatest quantity of radiolaria. Sediments poor in radiolaria are distributed in the 60° to 40°N limits; sediments in the central part of the north tropical region (40-15°N), are characterized by the lowest radiolarian content.

The quantitative distribution of radiolaria in sediments is shown in fig. 21 in relation to the depth of the ocean. The data obtained makes it possible to assert that the lowest concentrations of radiolaria (1,000 spec/g) are found in many samples at different depths in the 130 to 8,000 m range (in the Philippine Trench they were found at a depth of 10,610 m). Quantities of radiolaria greater than 10,000 spcm/g are typical principally of sediments deep than 2,000 m.; these greater than 100,000 spec/g (are characteristic of) 4-6 thousand m (depths).

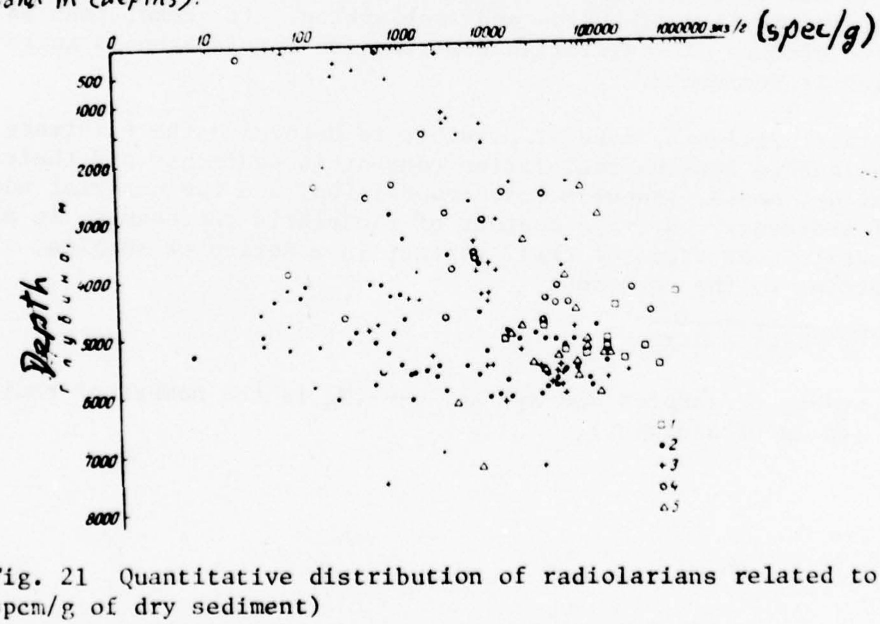


Fig. 21 Quantitative distribution of radiolarians related to depth (in spcm/g of dry sediment)

1. radiolarian oozes; 2. red clays; 3. terrigenous sediments; 4. foraminiferal sediments; 5. diatom oozes.

The low content of radiolaria in coastal regions and on submarine elev ations (at depths less than 1,000 m) can be explained by the dilution of radiolaria by terrigenous material and their low productivity in waters of abyssal sediments of the central part of the north tropical region of the Pacific Ocean.

Consequently, data confirm the existence of vertical zoning of radiolarian sediment deposits (Riedel, 1959a); Bezrukov, Lisitsyn, Petelin, Skornyakova, 1961). The relationship of radiolarian quantity and depth is not a typically direct relationship, but is manifested indirectly through accumulation of carbonate and terrigenous materials.

The question of the restriction of radiolaria to certain sediment fractions arouses great interest. The quantity of radiolaria was calculated for different fractions of seven sediment samples from different latitude zones in the ocean (table 2). Radiolarians were counted in the following fractions (in mm): greater than 0.1 fraction; 01-0.05 fraction 0.05-0.01 fraction. The pelite fraction (less than 0.01 mm) rarely contains complete skeletons of radiolarians; but mainly their fragments are found here. The possibility is not excluded that there are a few young stages of radiolaria or individual spicules in the pelitic fraction. Practically, however, one can assume the proportion of radiolaria in the greater than 0.01 mm fractions to be 100%.

Data in table 2 show that radiolaria are most frequently concentrated in the 0.1-0.01 fractions, i.e., in coarse and fine silt and, depending on the species composition of the fauna, principally in only one of these fractions.

It can be stated (see table 2), that the increase in percentage content of radiolaria in sand and coarse silt size in sediments of the north boreal region corresponds generally to the known rule that the size of radiolarians increases in colder waters.

TABLE 2. Distribution of radiolarians in different fractions of natural sediments (in %)

Station	Coordinates (Lat.)	(Long.)	Depth, (m)	Fractions, mm 0.1	0.1-0.05	0.05-0.01	Type of Sediment
3342	54°42'N,	164°30'E	4,588	49.4	28.5	22.4	Silty clay ooze
3327	53°03'N,	164°25'E	3,025	13.4	39.7	47.8	Coarse silt
4131	55°54'N,	145°25'W	3,955	1.7	17.3	81.0	Silty clay ooze
4124	54°27'N,	155°41"W	5,552	0.15	20.0	79.85	" " "
4074	40°24'N,	175°00'E	6,065	0.08	9.72	90.2	Clayey ooze
5124	7°55'N,	153°00'E	5,571	5.3	5.7	80.0	" "
5139	0°03'N,	176°07'E	5,530	1.5	16.2	89.2	" "

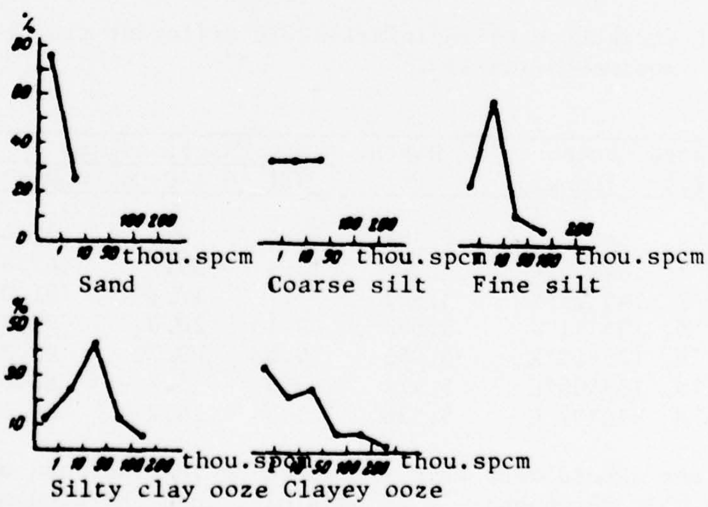
Consequently, one should keep this circumstance in mind when using radiolaria for paleogeographic purposes: it is possible, that the predominant concentration of radiolaria in large fractions of sediments could indicate that their deposition occurred under colder water conditions.

Gorshkova's (1952) data on the study of radiolaria by fractions in a core taken in the north boreal region, also testify to the increase of radiolaria in the sand and coarse silt fractions. In Antarctic sediments, radiolaria are of medium-and fine-sand and coarse-silt size (Petrushevskaya, 1961).

The distribution of radiolarians related to granulometric composition of sediments is shown in figs. 22-24. Figure 22 shows the frequency of occurrence of different radiolarian percentage content in sediments of different granulometric composition. The frequency of occurrence is the percentage of the total number of samples of a particular sediment type with a given radiolarian content.

Maximum radiolarian contents (>100,000 spcm/g) were found only in silty clay and clayey oozes, minimum values in sands and coarse silts. Radiolarian contents of 10,000-50,000 spcm/g are most typical of silt-pelite oozes. In the clayey (pelitic) silts the frequency of occurrence of various percentage content of radiolarians is comparatively equal, however radiolarian contents of 1,000-50,000 spcm/g are found more frequently than others. Low radiolarian contents occur most frequently in coarse sediments: 1000 spcm/g-in sands; 1000-10,000 spcm/g-in fine silt; the gradations mentioned and 10,000-50,000 spcm/g are found in almost the same frequency in coarse silt.

The quantitative content of radiolarians depends to a considerable degree on the type composition of the sediment (figs 23 and 24, table 3). Figure 23 shows the frequency of occurrence of different radiolarian contents in different types of sediments. The highest average radiolarian contents (251, 590 and 104,000 spcm/g) are typical of radiolarian-foraminiferal and radiolarian oozes. The next highest average concentration of radiolaria corresponds to weakly siliceous diatom oozes widely distributed in the North Pacific Ocean (29,000 spcm/g). Average radiolarian contents in terrigenous and foraminiferal sediments (3,410 and 2,550 spec/g, respectively) differ very little among themselves. Minimum average radiolarian content occurs in red clays. (1,580 spcm/g).



57/ Fig. 22. Frequency of occurrence (in %) of different radiolarian contents depending on the granulometric composition of the sediment.

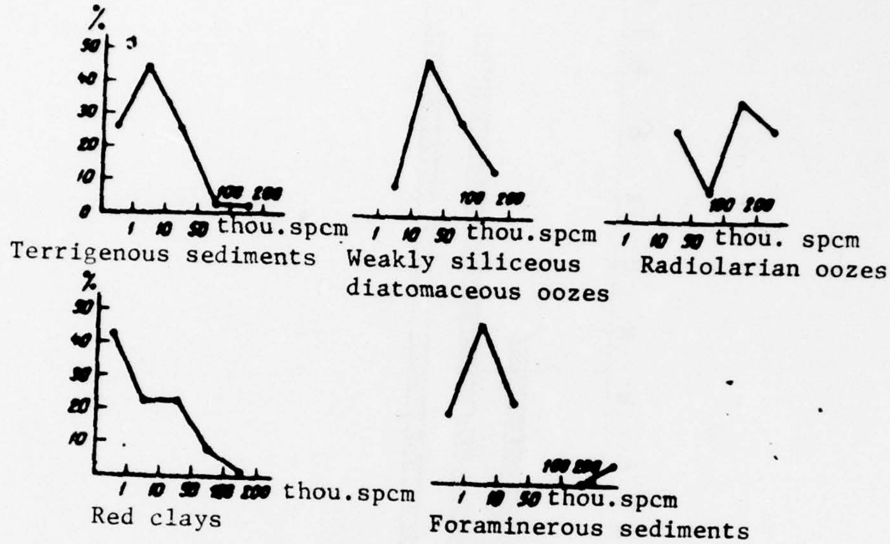
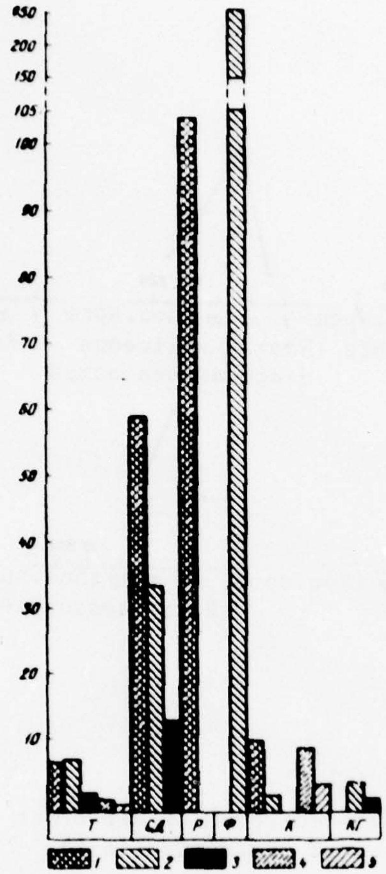


Fig 23. Frequency of occurrence of different radiolarian contents in different genetic types of sediments (in %).



58/ Fig. 24. Average radiolarian content in sediments of different granulometric and material composition (in thousands of spcm/g of dry sediment).

1 - clayey ooze; 2 - silty clay ooze; 3 - fine silt ooze; 4 - coarse silt ooze; 5 - sand
T - terrigenous sediments; CD - weakly siliceous diatom oozes; P - radiolarian oozes; ɸ - radiolarian-foraminiferal oozes of the equatorial zone; K - other carbonate sediments; KG - red clays

Table 3. Average content of radiolarians in sediments of different type composition (in spcm/g).

Sediments*	Q
Terrigenous	3,410
Weakly siliceous diatomaceous	29,000
Radiolarian	104,000
Radiolarian-foraminiferal	251,590
Foraminiferal	2,550
Red clays	1,580

*According to classifications in papers by Bezrukov, Lisitsyn, Petelin, Skornyakova (1961).

Radiolaria are distributed quite evenly within the limits of each genetic type of sediments (fig. 24). Maximum average concentrations of radiolaria in all types of sediments occurred in clayey and silty clay oozes, minimum - in sands. Figure 24 shows only those granulometric types of sediments that form each genetic type of sediment. The lack of samples containing radiolaria in some of the granulometric types probably is because not enough material was studied.

The relation of radiolarian content to granulometric composition of sediment reflects vertical zoning in the distribution of sediments. Coarse sediments (sands, coarse silts) that have typically low concentrations of radiolarians occur more frequently in shallow depths in coastal zones or on elevations. Low radiolarian contents in such regions result either from dilution by terrigenous or carbonate material or by washing out of radiolaria into finer sediments in hydrodynamically active zones (for example, low concentrations of radiolaria in Hawaiian Ridge sediments, compared with nearby sediments).

Maximum concentrations of radiolarians were found in regions of radiolarian
59/ and diatom oozes related, in turn, to regions of mass growth of phyto- and zooplankton (60° to 40°N and 10°N to 0°). These are deepwater sediments that correspond to pelite, silt-pelite, and fine silt oozes in granulometric composition. Outside the limits of diatom and radiolarian ooze distribution the content of radiolaria in sediments decreases sharply. An exception are radiolarian-foraminiferal sediments of the equatorial zone, where the radiolarian content is as high as the foraminiferal content.

In typical terrigenous and foraminiferal sediments of northern regions of the Pacific Ocean and in red clays, the radiolarian content is, as a rule, low. Low concentrations of radiolaria in red clays can be explained primarily by their restriction to regions of low biological productivity.

Consequently, in the distribution of radiolarians based on composite-genetic types, one can see proof of a general regular pattern inherent in the distribution of sediments related to climatic, vertical, and circum-continental zoning. "All three types of zoning complexly superimposed on each other are reflected in the composite and granulometric composition of sediments" (Bezrukov, Lisitsyn, Petelin, Skornyakova, 1961, p. 74).

Preservation of Radiolaria and Controlling Factors

The durability of radiolaria is very closely connected with their quantitative distribution.

Because ocean water is not saturated with silica, the skeletons of siliceous organisms begin to dissolve right after death. Consequently, the most dissolved and largest numbers of radiolarian skeletons are found in deep-water sediments (4,000-7,000 m) (fig. 25), especially in regions of low radiolarian productivity (in tropical and deep-water red clay regions). This is related also to the length of time, especially in regions with a low sedimentation rate, that radiolaria are subject to the dissolving effect of seawater during their descent to great depths. On the other hand, in regions of high plankton productivity and rapid sedimentation, radiolaria are better preserved even at great depths (the degree of disolution is less). An

exception are carbonate sediments, in which the percentage of semi-dissolved forms is quite high, even at depths less than 3,000 m.

The percentage content of partially dissolved radiolarians is lowest in diatom and terrigenous sediments. It seems that this is related to the fact that the thinner-walled diatoms, and especially their fragments, dissolve more easily, creating favorable conditions for the preservation of radiolarians. In general, it should be said that radiolaria in sediments of the boreal zone are several times better preserved than in warm-water regions. The same thing was noted by Petrushevskaya (1967).

It seems, that the rate of preservation of radiolaria can be explained by factors analogous to those affecting the preservation rate of diatoms. Diatom valves are protected from the dissolving action of water by an organic envelope containing organic silica compounds (Cooper, 1952). Diatom valves contain rapidly and slowly dissolving forms of SiO_2 (Lewin, 1959, 1961; Jorgensen, 1955). It is possible that the same phenomenon is responsible for the different dissolution rates of different parts of radiolarian skeletons
60/ (for example, "the cephalis" of the cirtoids, inner spheres of spheroids, and medullar shells of ponartids dissolve first).

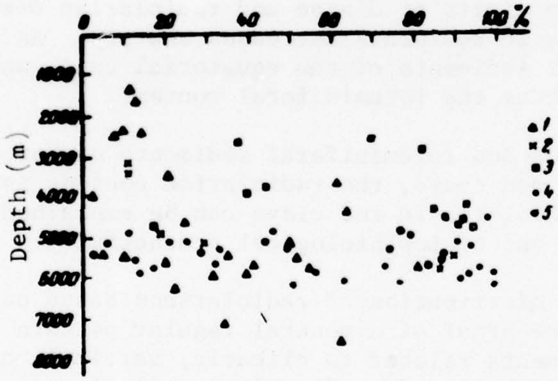


Fig. 25. Content of semi-dissolved radiolarian skeletons related to depth and types of sediments.

1 - terrigenous sediments; 2 - weakly siliceous diatom oozes; 3 - foraminiferal sediments; 4 - red clays; 5 - radiolarian oozes.

In Riedel's opinion (1959a), the accumulation of radiolaria and other siliceous organisms in sediments is facilitated by the inflow of pyroclastic material. Riedel thinks that the dissolution of pyroclastic material decreases the dissolution rate of siliceous skeletons that have settled to the bottom. The direct influence of volcanic material on increase in productivity of siliceous organisms occurs, according to Riedel, probably only in coastal regions of the ocean and in enclosed seas where silica, freed as a result of the dissolution of pyroclastic material, can quickly enter the upper water layers.

Mechanical damage to radiolaria (breaking off protrusions, etc.) can be related to the mechanical composition of sediments. Mechanical erosion of radiolaria can be explained not only by primary chipping of skeletons during original burial, but also by redeposition of sediments containing radiolaria caused by sediment slumping and density (turbidity) currents on the bottom.

Some Data on the Taxonomic Composition of Radiolarian Fauna

Radiolarians are distributed everywhere in the surface sediment layer of the North Pacific Ocean.

The following three orders were found in the faunal composition of radiolaria in sediments: Spumellaria, Nasselaria, and individual, rarely encountered Phaeodaria, which belong, respectively, to the genera Challengeria, Cadium, and Protocystis.

Throughout almost the entire area studied, radiolaria were represented by contemporary species. An exception are some sediments of the tropical belt of the ocean where Tertiary species are present in the radiolarian complex.

Contemporary knowledge about the radiolarian fauna of the World Ocean comes down, in essence, to only bits of information on their taxonomic composition. Until recently research has been quite inadequate, not only in the ecology and ranges of most species, but also in the distributional aspects of
61/ large taxonomic groups of radiolaria in the ocean[1].

As mentioned above, on the whole, radiolarian fauna are especially rich (quantitatively) in zones of increased total plankton productivity. Spumellaria and Nassellaria are equally abundant in these zones. Maximum concentrations of Nassellaria in sediments exceed 100,000 spcm/g, and the Spumellaria content was even higher than 200,000 spcm/g at two stations in the equatorial zone. Identically high concentrations of Nassellaria were noted in sediments in the Northwest Pacific Ocean (stn. 3246-41°39'N, 162°W).

The zone of minimum concentrations of Spumellaria and Nassellaria (<1,000 spcm) in sediments coincides with the zone of overall plankton low productivity (40°-20°N). Minimum contents of radiolaria also were noted in coastal regions of the entire northern basin of the Pacific Ocean. According to Fletcher and Weibull (cited from Khabakov, 1959), radiolaria are scarce not only in sediments, but also in plankton of coastal regions.

Concentrations of Spumellaria and Nassellaria of 10 to 50 thousand spcm/g are peculiar to sediments of the greater part of the Pacific Ocean boreal zone. At the same time, somewhat higher concentrations of Nassellaria are typical of the northeastern part of the ocean (compared to the northwest).

The data in table 4 indicate that (1) the quantitative distribution of radiolaria of the orders Spumellaria and Nassellaria is related to latitudinal zoning of the ocean and (2) the distribution of both orders are similar.

[1] The statement applies to the orders Spumellaria and Nassellaria. The order Phaeodaria was fully and adequately studied. Furthermore, Reshetnyak (1966) classified waters of the World Ocean based on studies of Phaeodaria.

Table 4. Frequency of occurrence (in %) of different concentrations of Spumellaria and Nassellaria in different latitude zones of the ocean.

Ocean zones	Nassellaria (thou. spcm/g)					Spumellaria (thou. spcm/g)					
	<1	1-10	10-50	50-100	> 100	<1	1-10	10-50	50-100	100-200	<200
60°-40°N	24.3	37.0	33.0	4.3	1.4	24.0	40.7	31.0	4.2	-	-
40°-15°N	61.0	25.0	11.0	1.5	1.5	63.7	18.8	14.5	1.5	1.5	-
15°-0°N	21.8	26.1	30.5	8.6	13.0	17.4	34.5	34.8	-	8.4	4.3

In spite of close correspondence in the quantitative distribution of both groups, Nasselaria and Spumellaria do not always participate equally in the sedimentation processes in different regions. From the charts of relative Spumellaria and Nassellaria content in the sediments (fig. 26), as well as in table 5, one can see the following.

Minimum concentrations of Nasselaria (10-20%) and corresponding maximum concentrations of Spumellaria (80-89%) characterize sediments of some stations in the western tropical zone of the Pacific Ocean. The maximum relative content of Nassellaria (corresponding to a Spumellaria content of <25%) is confined to certain sediments of the equatorial zone (15.1% frequency of occurrence) and the northwest ocean. However, at several stations in the equatorial zone (5.9% frequency of occurrrence) Spumellaria comprise >75% of the radiolarian complex. Spumellaria predominate in sediments of the tropical
62/ zone (40°-15°N), whereas Nassellaria usually (89.8%) comprise <50% of the radiolarian complex.

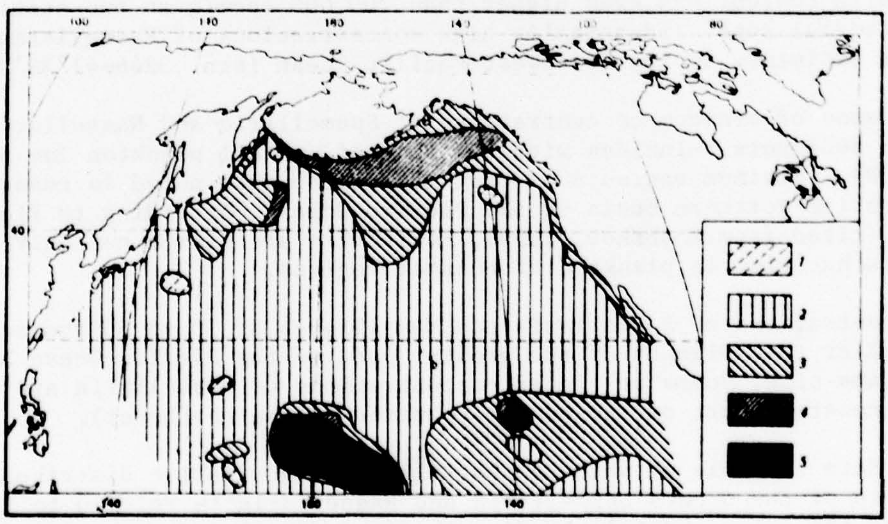


Fig. 26. Relative content of Nassellaria in sediments of the northern Pacific Ocean (in % of the total quantity of radiolarians).

1. <20; 2. 20-50; 3. 50-60; 4. 60-75; 5. >75.

In the boreal zone, the predominance of Nassellaria over Spumellaria is more obvious: the former comprise >50% of the complex in sediments at most stations (57.4%). Figure 26 and tables 4 and 5 show that Nassellaria predominate absolutely and relatively in zones of high plankton production.

Table 5. Frequency of occurrence (in %) of relative contents of Spumellaria and Nassellaria in different latitude zones of the ocean.

Ocean Zone	Spumellaria (%)					Nassellaria (%)				
	<20	20-50	50-60	60-75	>75	<20	20-50	50-60	60-75	>75
60°-40°N	-	53.7	25.9	18.5	1.9	3.7	38.9	27.8	64.1	5.5
40°-15°N	-	10.3	5.1	64.1	20.5	12.8	77.0	7.6	2.6	-
15°-0°N	14.7	44.2	23.5	11.7	5.9	9.1	36.4	31.4	9.1	15.1

Correlations of Spumellaria and Nasselaria in sediments and plankton turned out to be very similar. Studies of radiolaria in suspension in equatorial regions of the Pacific Ocean revealed the significant predominance of Nassellaria over Spumellaria in the water column: Nassellaria comprised 82-87%, while Spumellaria comprised 13-18%. In sediments at the same stations, Nassellaria comprised approximately 65% (Petrushevskaya, 1966).

Until recently, the relative abundance of spherical and cirtoid forms was mistakenly adopted by many geologists as an indicator of age (Ishikawa, 1950). Data on the distribution of Spumellaria and Nassellaria in Pacific Ocean
63/ bottom deposits (fig. 26) confirms Khabakov's (1959) assumption on the influence of ecological factors on the relative population density of these radiolarians. However, the question of what these factors are can hardly be solved permanently at this time, because there are very little data on the physiology and morphological and functional adaptability of radiolarians.

The main mass of radiolarians in sediments of the northern basin of the Pacific Ocean consists of representatives of three groups: among Nasselaria they consist of the suborder Cyrtellaria (mainly Cyrtoidae fam.), and among Spumellaria they consist of Discoidea and Larcoidea. The quantitative content of radiolarians of each group changes in different zones of the ocean depending on the character of the fauna as a whole. All three groups of radiolarians may be represented equally, or one of them can predominate.

The CYRTOIDS (Cyrtoidae fam.) are usually the most numerous, especially maximum concentrations of radiolaria. In the northwestern oceans, Cyrtoidae sometimes comprise more than 50% of all fauna. Overall, the suborder Cyrtellaria is the most numerous and diverse radiolarian group in the boreal zone; all families of this suborder are found in the sediments.

In the equatorial zone, Cyrtoid content in radiolarian oozes usually is also very significant. At stn. 5139, the Cyrtoidae comprised a 77% share of the total quantity of radiolarians. According to Petrushevskaya's data (1966, 1967), Cyrtoidae comprised 53% to 67% of the suspended matter at three stations in the same region.

The DISCOIDS (suborder Discoidea) predominate in quantity much less frequently (for example, at stn. 3866-5°02'N, 172°16'E-71%, stn. 5153-1°N, 160°E-67%). Usually their predominance is not as sharply evident. Discoidea are, as a rule, diverse and abundant south of 40°N.

Although, the Discoidea are numerous, they are represented mainly by porodiscids and spongodiscids in the boreal zone sediments. Radiolaria of the genus Heliodiscus are very rarely found, mainly in the southern part of this zone. Radiolaria of the families Cenodiscidae, Phacodiscidae, and Coccodiscidae families are absent in boreal zone sediments.

The larcoids suborder (Larcoidea) frequently form a significant part of the radiolaria. At station 3634 (12°44'N, 153°51'E), Larcoidea comprised 25.1% of the total radiolarian content of 80,800 spcm/g, while at station 3451 (37°27'N. 146°54"E) they formed 22,2% of the total radiolarian content of 36,540 spcm/g. Larcoidea are most diverse in the warm water regions. Colonial Spumellaria appear in large numbers together with Larcoidea in sediments at some stations (mainly along 20°N). Larcoidea found in sediments of the boreal zone belong mostly to the family Lithelidae. Radiolarians of the family Pylonidae occur infrequently, and principally in sediments of the southern part of this zone.

The suborder Prunoidea plays a quantitatively less significant role compared with Cyrtoidae, Discoidea, and Larcoidea. In sediments of the northern part of the Pacific Ocean, the Prunoidea content usually does not exceed 5-7% and, more rarely, 10% of the total number. In extremely rare cases, Prunoidea content can be higher (at stn. 3342-54°29'N, 164°30'E-21.2%).

In boreal zone sediments, Prunoidea are represented by species belonging to the familes Druppulidae and (to a lesser extent) Ellispidae. The families Cyphinidae, Panartidae, and Zygartidae are absent in sediments in this zone.

64/ The role of spherical forms (suborder Sphaeroidae) is even less significant in the overall quantitative radiolarian distribution. Based on data from a study of radiolarians in suspension (Petrushevskaya, 1967, 1966), the suborders Larcoidea (3-8.5%) and Discoidea (3 to 7%), including the family Porodiscidae (2.5%), are most numerous among Spumellaria in the water column of the equatorial Pacific Ocean; Sphaeroidae comprise approximately 5% there, while the suborder Prunoidea (comprises)-1%.

Spyroidae and Stephoidae radiolarians do not comprise a significant part of radiolarian fauna in sediments of most of the bottom of the northern basin of the Pacific Ocean. However, at some stations in the equatorial zone, their content increases to 23-39.2% of the total radiolarian content. In suspensions (water samples) at several stations near the equator (Petrushevskaya, 1966, 1967), Stephoidae comprise 9-13%, while the proportion of Spyroidae is several times smaller (according to the diagram in the same report).

The correlation between different groups of radiolarians in sediments changes, to some extent, due to dissolution of the thinner-walled radiolarians during their descent to the bottom. As already mentioned, Spyroidae and Stephoidae play a significant role in sediments at several stations in the

equatorial zone of the Pacific Ocean. The presence of outcrops of ancient deposits directly on the surface of the ocean bottom or considerable intermixing of recent and ancient forms caused by erosion of the bottom by density (turbidity) currents, is typical of this zone (Riedel, 1951, 1954, 1957, 1959b; Riedel, Funnel, 1963; see also Chapter I). The content of Spyroidae and Stephoidae increases noticeably in these deposits (table 6)[1].

65/ Table 6. Content of the families Spyroidae and Stephaidae radiolarians in some deposits of the equatorial zone

Name of expedition, station number	Coordinates	Depth (m)	Age of radiolarians	Spyroida & Stephoidae content, (%)
Midpac-72	12°48'N, 134°26'W	4760	Eocene mixed with Contemporary forms	27.3
c/s Vityaz 5069	13°55'N, 140°36'W	4993	" " " "	34.7
5071	12°10'N, 140°37'W	4910	" " " "	29.6
5074	10°30'N, 140°01'W	4858	Early Oligocene mixed with Eocene forms	23.9
5133	5°58'N, 176°04'W	5416	Eocene mixed with Miocene forms	39.2
3869	9°17'N, 173°03'E	5220	Miocene mixed with Eocene forms	39.5
Chubasco-7	11°10'N, 125°34'W	4645	Contemporary mixed with Oligocene forms	
e/s Vityaz'				
5124	7°55'N, 153°04'W	5571	Contemporary mixed with Oligocene forms	
5126	11°17'N, 154°07'W	5142	Contemporary mixed with Eocene forms	

Two species complexes, boreal and tropical can be distinguished among contemporary radiolaria of the northern part of the Pacific Ocean. The distribution boundary of both complexes passes approximately along 40°N.

[1] The author is very grateful to Dr. Riedel of Scripps Institution of Oceanography for his help in the age determination of ancient radiolaria.

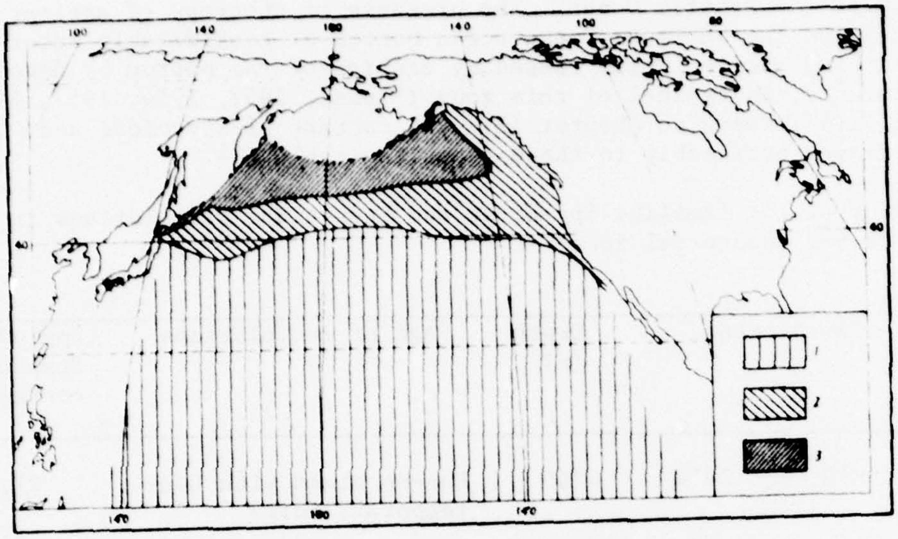


Fig. 27. Faunal radiolarian complex in the surface sediment layer.

1-tropical complex; 2-mixed complex; 3-boreal complex

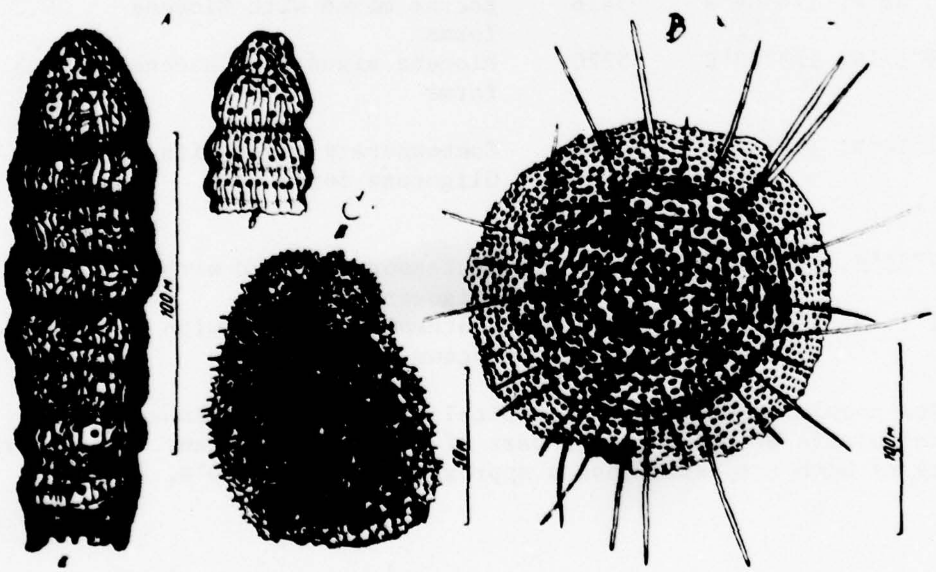


Fig. 28. Typical species of radiolaria in sediments of the northern Pacific Ocean.

A - Lithonutra arachnea (Ehr.); a - in sediments of boreal zone; b - in sediments of tropical zone; B - Stylochlamidium venustum (Bailey); C - Botryocyrtis scutum (Harting)

66/ It appears as a reasonably wide zone. The boundary zone fauna are mixed; comprised partly of boreal complex forms and partly of tropical complexes species. In the North Pacific, the distribution of radiolarian complexes in sediments of the northern basin of the Pacific Ocean is determined by characteristics of the hydrologic regime (Fig. 27).

Boreal radiolarian fauna are confined mainly to sediments north of 40°N. In the western ocean, the boundary of boreal fauna descends to 41°N (along 142°E) but in the east, it rises to 54°N.

The faunal base consists of species that are very numerous and whose maximum occurrence is within the limits of the boreal zone (mass species):

Lithomitra arachnea (Ehrenberg)
Artostrobus annulatus (Bailey)
Lithocampe aquilonaris (Bailey)
Lithocampe platycephala (Ehrenberg)
Chromiodruppa (?) sp.
Lithomelissa sp.
Cycladophora davisiana (Ehrenberg)
Stylodictya stellata (Bailey)
Stylochlamidium venustum (Bailey)
Ceratospyris borealis (Bailey
Spongopyle osculosa Dreyer
Cyrtocapsa (?) cuspidata (Bailey)
Spongurus conf. pylomaticus Riedel
Echinomma delicatulum (Dogiel)
Echinomma popofskii Petrushevskaya
Cromyechinus borealis Cleve
Peripyramis circumtexta Haeckel
Cenosphaera cristata Haeckel
Cycladophora sp.
Cycladophora cornuta (Bailey)
Stylatractus sp.
Dictyophimus clevei Jorgensen
Dictyophimus gracilipes Bailey
Saccospyris sp. 1
Saccospyris sp. 2
Dictyocephalus papillosus Ehrenberg

An insignificant part of boreal complex species occur principally in the boreal zone, whereas most of them can be found in sediments of the borea and tropical zones of the ocean. However, widely distributed boreal complex forms predominate quantitatively in boreal zone sediments, where the maximum number of these species occurred.

As an example of both types of ranges the ranges of Lithomitra arachnea (Ehrenberg) and Stylochlamidium venustum (Bailey) are presented.

We accept the limits of Lithomitra arachnea (Ehrenberg) (Fig. 28 A, a&b) as defined by Riedel (1958); Eucyrtidium lineatum arachreum: Ehrenberg, 1862, p. 299; Lithomitra lineata (Ehrenberg): Haechel, 1887, p. 1484 (partim); Cleve, 1899, p. 30, pl. 2, fig. 7; Lithomitra nodosaria: Haeckel, 1887,

p. 1484, pl. 79, fig. 1; Lithomitra vanhoffeni: Popofsky, 1908, 296, pl. 36, fig. 9. It should be emphasized, however, that the significant morphological variability of L. arachnea, as well as gaps in its distribution range, raise some doubts about the unity of this species.

68/ L. arachnea (fig. 29) occurred in sediments at 108 stations (p = 61.5%) in quantities of 20 to 23,280 spec/g. This is the greatest mass type species in sediments north of 40°N (89.5% frequency of occurrence). The maximum content of the species reaches 58.2% of the total radiolarian content. The content of L. arachnea in sediments decreases as one moves from high latitudes to the tropics; however, in boreal zone sediments, concentrations of this species do not usually decrease below 10%. L. arachnea has not been found in sediment samples from the tropical zone, except in a small spot in its southeastern part. South of 20°N, the concentration of L. arachnea in sediments reaches a maximum of 2.5% (stn Chubasco = 7°-11°10'N, 125°34'W). South of 20°N, the L. arachnea content generally does not exceed 1% of the total number of radiolaria per gram of sediment.

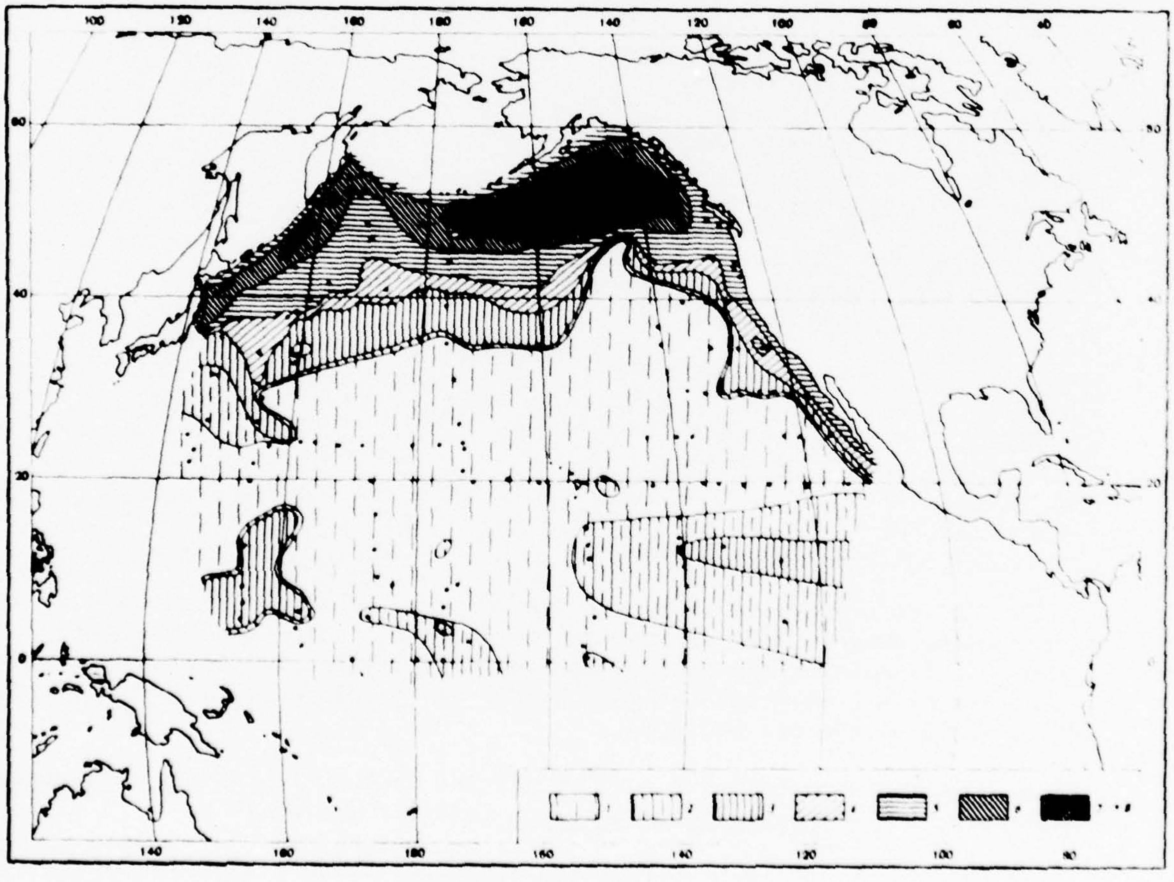
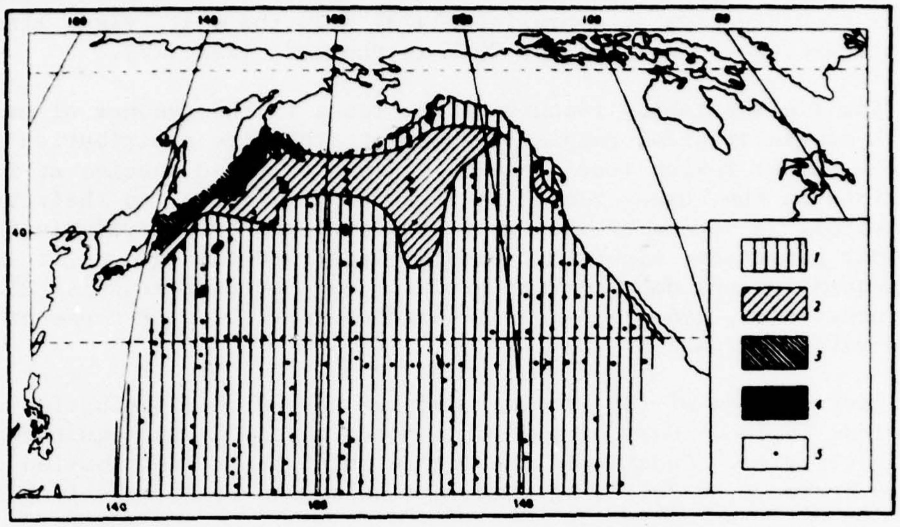


Fig. 29. Lithomitra arachnea (Ehrenberg) in sediments of the northern Pacific Ocean (in % of the total faunal content).

1. Species not encountered; 2. 1; 3. 1-5, 4. 5-10; 5. 10-20; 6. 20-25; 7. 25-60; 8. stations studied.



68/ Fig. 30. Stylochlamidium venustum (Bailey) in sediments of the northern Pacific Ocean (in % of total faunal content).

1. species not found; 2. 1; 3. 1-3; 4. 3; 5. stations studied.

This species is known to exist in plankton and bottom sediments of the Antarctic, North Pacific and Atlantic Oceans, Bering Sea, and tropical parts of the Pacific and Indian Oceans (Haeckel, 1887; Cleve, 1899; Riedel, 1958; Petrushevskaya, 1966). This species has been found in plankton at different depths: in the North Atlantic at depths of 2,600-0m, 400-0m, and 230-0m (= L. lineata Cleve, 1889), in the Antarctic at depths of 0-200 and 1,000 m; (Popofsky, 1908; Petrushevskaya, 1967), in the Bering Sea at depths of 1,500-1,050 m (=L. nodosaria, according to V. A. Dogel's data), and at depths of 5,513-4,074 m in the tropics (= L. nodosaria Haeckel, 1887).

According to Petrushevskaya's data, L. arachnea occurred exclusively in Antarctic sediments, in deep water (10-15% of the total radiolarian content). In tropical regions of the Indian Ocean, L. arachnea shells are comparatively rare and do not comprise a definite part of the total radiolarian content.

We adopted Stylochlamidium venustum (Baily) (see fig. 28, B) within the limits of these species: Perichlamidium venustum: Bailey, 1856, table I, figs. 16 and 17; Stylochlamidium venustum: Haeckel, 1887.

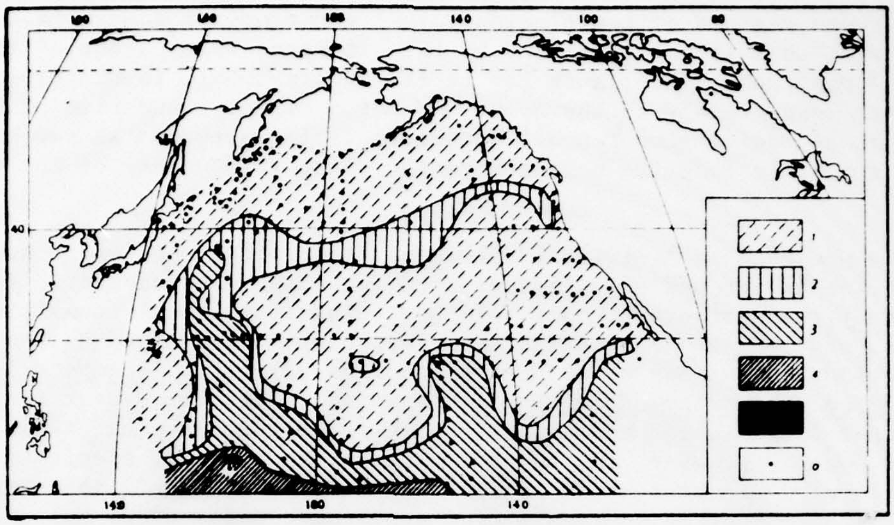
69/ In the north parts of the Pacific ocean, S. venustum is confined (fig. 30) to sediments located mainly north of 40°N (except for several stations somewhat south of it). This species occurred in sediments at 41 stations (23.3% in quantities of 20 to 1,070 spcm/g; however, low concentrations (100) were found at only 15 stations. The content of S. venustum in percent of total radiolarian faunal content fluctuates within 6.3 to 0.04% limits (more than 1% at 20 stations). This species was first discovered by Bailey (1856) in the Pacific Ocean near Kamchatka. Petrushevskaya thinks that the forms of Stylochlamidium sp. she found south of 45°S in Antarctic sediments are close to Perichlamidium venustum Bailey.

Tropical radiolarian fauna are distributed in sediments south of 40°N. Their boundary lies at approximately 37°N in the west, rises almost to 44°N in the center, and descends to 30°N in the east (fig. 27).

The distinguishing feature of the fauna is the absence of mass species. Not a single tropical complex species attains wide distribution in sediments of the boreal region (the presence of some of these species at individual stations in the boreal region is related, apparently, to their transport by currents). A series of systematic groups lives exclusively in the tropical region: panartids, zigartids, euchitoniids, and some groups of larkoids. Consequently, our data confirm Riedel's and Petrushevskaya's (Riedel, 1958; Petrushevskaya, 1967) opinions about the restriction of these groups to warm water habitats.

Most species of the tropical complex have wide distribution within the tropical region. Part of the forms occur mainly in the equatorial zone of this region. Judging by the character of their distribution on the ocean bottom, the following organisms belong to the tropical species complex:

Actinomma medianum Clark
Actinomma arcadophorum Haeckel
Heliodiscus asteriscus Haeckel
Heliodiscus echiniscus Haeckel
Spongaster tetras (Ehr.) irregularis Negrini
Spongaster tetras tetras Ehrenberg
Sponaster sp.
Amphiropalum sp.
Euchitonea mulleri Haeckel
Euchitonia elegans (Ehrenberg)
Stylodictya micrommma (?) Haeckel
Larcospyra sp.
Genus Tetrapyle and forms of genus Monozonium
Panartus tetrathalamus Haeckel and in general the families Artiscidae
Cyphinidae, Panartidae, Zygartidae
Genus Carpocanium
Theoconus zancleus Haeckel
Theoconus hertwigii (Haeckel)
Lampocyclas maritolis maritalis Nigrini
Lampocyclas maritalis polypora Nigrini
Lithopera bacca Ehrenberg
Anthocyrtidium ophirense (Ehrenberg)
Psylomelissa phalakra Haeckel
Tricolocampa cylindrica Haeckel
Theocorythium trachelium trachelium (Ehrenberg)
Theocorythium trachelium (Ehr.) dianae (Haeckel)
Pterocanium praetextum praetextum (Ehr.)
Pterocanium praetextum (Ehr.) eucolpum (Hck.)
Eucyrtidium acuminatum (Ehr.)
Eucyrtidium hexagonatum (Hck.)
Lithocampe sp.
Botrycyrtus scutum (Harting)
Eucoronis sp.
Amphispyris reticulata (Ehr.)
Colonial spumellaria



70/ Fig. 31. Botryocyrtis scutum (Harting) in sediments of the northern Pacific Ocean (in % of total fauna content)

1. species not found; 2. 1; 3. 1-5; 4. 5-10; 5. 10; 6. stations studied.

One of the *typical species* of the tropical complex is, judging by its range, Botryocyrtis scutum (Harting) (fig. 28C). We accept Botryocyrtis scutum (Harting) within the limits adopted in Nigrini's work (Nigrini, 1967);- Haliomma scutum (Harting, 1864, table 1, fig. 18); Botryocyrtis caput-serpentis (Ehrenberg, 1872a); B. caput-serpentis (Ehrenberg, 1873, pl. X, fig. 21); B. serpentis Ehr. (Haeckel, 1887); Botryopyle hexapora Popofskiy (Petrushevskaya, 1964, figs. 4 & 5); Botryocrtis caput-serpentis Ehr. (Petrushevskaya, 1965a); Botryocyrtis caput-serpentis Ehr. (table 6, figs. 1a & 1c).

In the North Pacific (fig. 31), this species occurred in sediments south of 40°N (33.9% occurrences) in quantities of 20 to 11,680 spec/g. The content of B. scutum, in percent of total quantity of radiolaria, fluctuated within 10.8-0.15% limits. The most frequent occurrences and maximum content were in tropical zone sediments and, especially, near the equator (south of 15°N-64.7%).

B. scutum (=Halioma scutum), found in the Banda Sea, was first described by Harting (1864) in the Banda Sea (Malay Archipelago). The species were found by Ehrenberg (=B. caput-serpentis) (1860b) in the North Pacific Ocean (20°52'N, 151°50'W, depth-4,755 m; 30°51N, 130°08'W, depth-4,755 m) and in Indian Ocean sediments (5°37'S, 61°33'E, depth-4,023 m). Haeckel (1887) found this species (=B. serpentis) in the Indian Ocean at a depth of 3,658 m, Perushevskaya (1965) (=B. caput-serpentis)-in the Indian Ocean in suspension at the surface, and in the Pacific (stn. 5117, 5124 horizons 25, 50, 100, 300 m), and by Nigrini-in Indian Ocean sediments (Nigrini, 1967). According to Nigrini, the species is very abundant in low latitudes. South of 20°S the content of the species decreases sharply, and south of 35°S, it is practically absent.

Between regions of radiolarian boreal and tropical faunas is a wide faunal zone that is characterized by the simultaneous presence of radiolaria of both complexes. This fauna can be called mixed. It is distributed in sediments respectively to the south and north of the boundaries of boreal and tropical radiolarian fauna. Numerical ratios between the two complexes change gradually from the northern to the southern boundary of the transitional zone.

The presence of individual specimens of tropical species in sediments against the background of a typical boreal complex was considered to be the feature of the northern boundary of the radiolarian faunal transitional zone. The northern boundary of the transitional zone is determined by the presence of individual specimens of Theoconus zancleus (?), Tricolocampa cilindrica, Eucyrtidium acuminatum, Actinomma medianum and other warm-water forms. Warm-water forms in the sediments acquire greater importance as one goes farther south. However, in the entire transitional zone, species of the boreal complex are present in insignificant numbers. The line along which radiolarian content in sediments of the boreal complex drops below 5-7% and the frequency of occurrence of typical species sharply decreases, can be adopted as the southern border of the transitional zone.

Because quantitatively, the basis of boreal fauna consists of widely distributed species, quantitative evaluation of boreal complex participation (percentage comtent of the complex) is a determining factor in definition of transitional zone boundaries.

Conclusions

1. Quantitative distribution of radiolaria in the surface sediment layer depends on the following factors: (a) productivity of radiolaria in water, (b) preservation conditions, (c) dilution by terrigenous and carbonate material.

2. The quantitative distribution of radiolaria in the surface sediment layer reflects their distribution in North Pacific waters, as well as general features of zooplankton distribution in the ocean (Bogorov, 1958, 1959; Bogorov, Vinogradov, 1960; Beklemishev, Lubny-Gertsyk, 1959; Beklemishev, 1961).

In the North Pacific, the greatest plankton biomass occurs north of 40°N, which is reflected in the sediments. The low concentration of radiolaria in sediments between 40°-15°N is in complete accord with the general low population density of phyto- and zoo-plankton in tropical waters; this is caused by the exceptionally low content of biogenic elements in the waters.

In addition, in tropical regions where red clay typically forms, the initial scarcity of radiolarian fauna that reach the bottom is enchanced by subsequent processes of dissolution of radiolarian skeletons in sediments. In red clays, siliceous skeletons of radiolaria are subject to dissolution due to extremely slow sedimentation rates. Accumulation of radiolarian oozes in the equatorial zone of the Pacific Ocean is facilitated by the locally abundant growth of radiolaria in the water column and the correspondingly high sedimentation rates (Riedel, 1959; Petrushevskaya, 1967). Zhuze (1962) came to the same conclusion while studying diatoms in bottom sediments of the North
72/ Pacific Ocean. However, it seems that radiolaria dissolve in sediments more slowly than diatoms.

3. The confinement of radiolaria to specific material and genetic types of sediments is determined, in the final analysis, by the zonal character of plankton distribution. Maximum concentrations of radiolaria in the North Pacific Ocean occurred in areas of radiolarian, radiolarian-foraminiferal, and weakly siliceous diatom oozes, while minimum concentrations occurred in terrigenous and foraminiferal sediments and red clays.

The pattern, of radiolarian distribution in sediments reflects the distribution of radiolaria among plankton in the North Pacific Ocean. However, real correlation between radiolaria in plankton and in sediments are biased somewhat, by the process of dilution in sediments. Low concentrations of radiolaria in terrigenous sediemtns of the coastal belt can be explained, not only by the significant dilution by fragments, but probably also by the actual scarcity of radiolarians in plankton in coastal waters. At the same time, in plankton, the true character of radiolarian distribution is, to some extent, masked by the high foraminiferal content of sediments.

4. The data obtained make it possible to form an idea about the geographic distribution of Nassellaria and Spumellaria. In sediments of the North Pacific Ocean, two types of radiolarian fauna can be distinguished, boreal and tropical. A mixed complex exists between the distribution regions of the two groups mentioned.

5. Higher concentrations of radiolaria in low latitude sediments and their extremely high species diversity there, compared to high latitudes, testifies to the warm-water nature of radiolarian fauna as a whole.

The zonal character of distribution of radiolaria suggests their use in stratigraphic and paleogeographic interpretation of sedimentation conditions. The almost complete absence of data on ecology, geographic distribution, and ontogeny of most radiolarian species is a great impediment to development of the radiolarian method (of dating and definition of environment) in marine geology. These problems can be solved only by additional studies of radiolaria in the water column. Suspended matter in ocean water should be an important source of information about radiolarian fauna.

In the future we will need special studies of radiolaria in plankton of the Pacific Ocean; these will be necessary to understand all aspects of their distribution in bottom deposits.

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Chapter III

Planktonic Foraminifera in the Surface Sediment Layer of the Pacific Ocean

Introduction

Planktonic foraminifera are single-cell organisms with calcareous shells. They are widely distributed in ocean waters and, after they die and settle (on the bottom), they play an exceptionally important role in the formation of pelagic sediments. Planktonic foraminifera are one of the main sources of calcium carbonate deposition. Their close connection with environmental conditions and wide distribution in sediments determines their great importance in stratigraphy and paleogeography, and in defining sedimentation conditions. This chapter discusses features of the distribution of planktonic foraminifera in the surface layer of contemporary sediments of the Pacific Ocean.

History of Research

Distribution of Planktonic Foraminifera in Pacific Ocean Waters

The quantitative distribution of planktonic foraminifera in Pacific Ocean waters has been investigated by Bradshaw (1959) in the northern part of the ocean and by Parker (1960) in the southeastern. Based on a study of species distribution in the surface water layer in the northern and equatorial parts of the Pacific Ocean, Bradshaw identified the following faunal complexes of planktonic foraminifera (fig. 32).

Subarctic (cold-water) fauna are distributed north of the polar front (40-45°N). This fauna contains typical cold-water species--*Globigerina pachyderma* (Ehrenberg), *Globigerinoides* cf. *G. minuta* Natland--and species producing maximum concentrations in subarctic waters, but also found south of the polar front: *Globigerina bulloides* Orbigny, *Globigerinita glutinata* (Egger), *Globigerina quinqueloba* Natland.

A transitional fauna was found between the 15° and 20°C summer isotherms south of the polar front. This fauna contains elements of subarctic, as well as warm-water fauna. The species composition is determined by proximity to the southern or northern boundary and the degree of intermixing. The most characteristic species are *Globigerina bulloides* Orbigny, *Globigerina eggeri* Rhumbler, *Orbulina universa* Orbigny. A few warm-water species, *Globigerinella aequilateralis* (Brady) and *Globigerinoides ruber* (Orbigny), appear.

South of the transitional fauna, Bradshaw found two warm-water fauna--central and equatorial. The 20°C isotherm is the boundary between these faunas in the northern hemisphere. Central fauna are typified by the species *Globigerina inflata* Orbigny and *Globigerina truncatulinoides* (Orbigny). Equatorial fauna are represented by *globigerina conglomerata* (Schwager), *Globorotalia tumida* (Brady), *Sphaeroidinella dehiscens* (Parker and Jones), and *Pulleniatina obliquiloculata* (Parker and Jones).

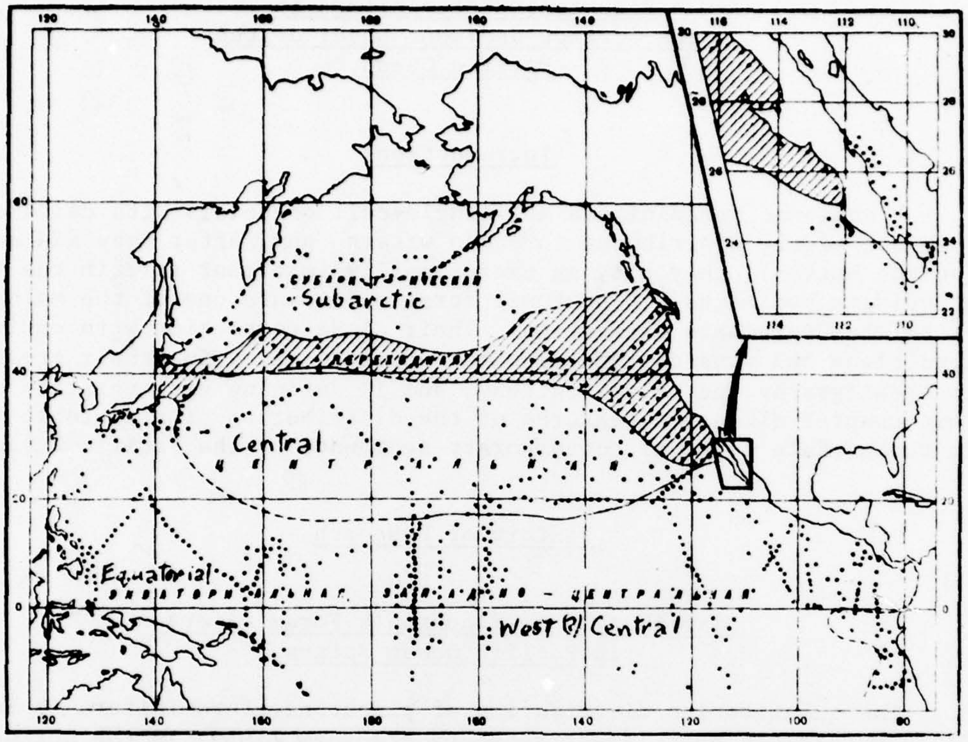

Fig. 32. Planktonic foraminiferal fauna in Pacific Ocean waters (after Bradshaw, 1959).

In the southeast part of the Pacific Ocean equatorial forms are identified--Globigerina conglomerata, Globigerina hexagona Natland, Globorotalia menardii (Orbigny), Pulleniatina obliquiloculata--, the equatorial and south-central species--Globigerina bulloides, Globigerina inflata, Globorotalia, punctulata (Orbigny), Globorotalia punctulata (Orbigny), Globorotalia truncatulinoides--, and the subantarctic species:--Globorotalia scitula (Brady) (Parker, 1960).

Quantitative distribution of planktonic foraminifera differs in the faunal-complexes identified (figs. 33-35). It was studied from plankton samples that were collected in nets of different types: standard metric, dump (17 cm in diameter), and Clark-Bumpus. Mesh diameter of the metric net was 0.31-0.55 mm (flour mill gauge No. 56 and 30). The mesh diameter of the other two nets ranged from 0.07 tp 0.14 mm. Clark-Bumpus and dump nets were used mainly in the northern parts of the ocean (areas of small forms; while metric nets were used in the tropical and equatorial zones (fig. 34) where large forms are distributed. Data on the distribution of foraminifera in the southeastern parts of the ocean are presented in fig. 35.

The subarctic region (north of 40°-45°N) is characterized by large populations of foraminifera (greater than 100,000 spcm/1,000 m^3 of water) with small number of species (fig. 33). In the transitional zone, the number of species increases, but populations of foraminifera are smaller than in the subarctic. The central water masses are characterized by minimum concentrations of foraminifera (less than 1,000 spcm/1,000 m^3 of water).

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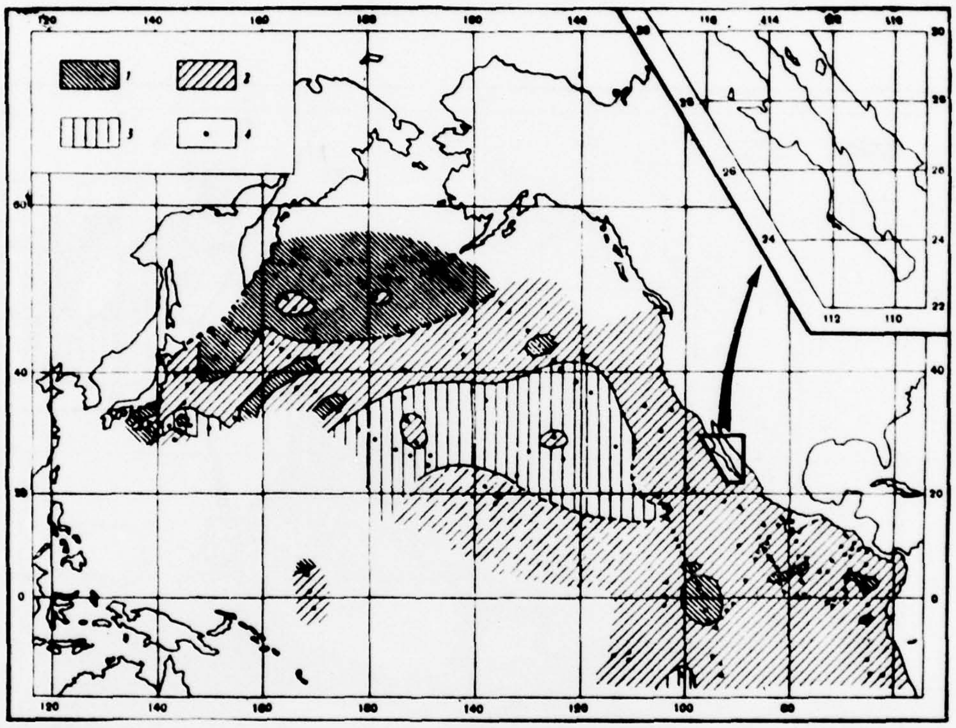

Fig. 33. Total quantitative distribution of planktonic foraminifera in North Pacific waters (catches made with Clark-Bumpus and dump nets) (after Bradshaw, 1959).

1. >100,000/1,000 m^3; 2. 10,000-100,000/1,000 -m^3; 3. 1,000-10,000/1,000 m^3; 4. sample locations

In the equatorial zone, the distribution of planktonic foraminifera is very heterogeneous (fig. 34). High concentrations of foraminifera (greater than 1,000 spcm/1,000 m of water) occur in currents of the equatorial system (from 10°N to 15°S); in the remaining regions, the quantity of foraminifera is lower than in subarctic waters. In the southeastern part of the ocean, foraminiferal populations are smaller than they are in the north (fig. 35).

Data on the distribution of total quantities of foraminifera and on individual planktonic foraminiferal species in ocean waters, as well as on restriction of species to various water masses, were used in the present work to correlate with the distribution of planktonic foraminifera in sediments of the Pacific Ocean.

The vertical distribution of planktonic foraminifera in the 0 to 400 m layer of Pacific Ocean water was studied by Bradshaw. He established that foraminifera were generally confined to the 0-100 m water layer and that maximum population density occurred in the 6-30 m interval. Comparatively low concentrations were noted at depths greater than 200 m. Parker obtained analogous data in the South Pacific, where the greatest concentrations of planktonic foraminifera are confined to the 0-200 m layer. High concentrations in the 0-200 m layer and highest concentrations in the 25-50 m layer has also been noted in the Indian Ocean (Belyayeva, 1964).

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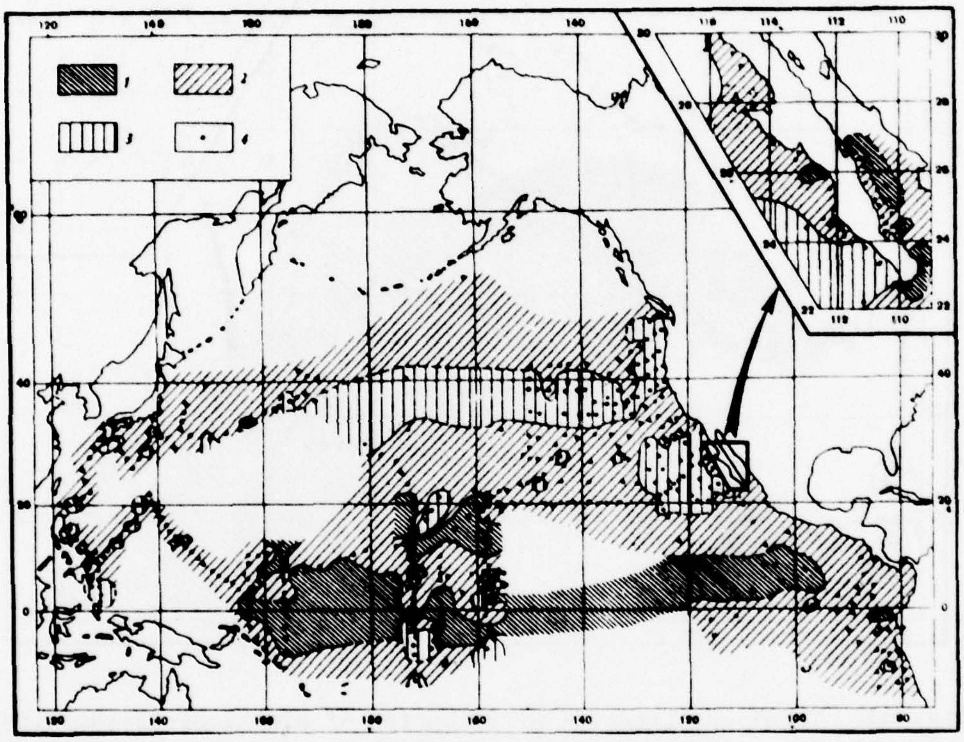

Fig. 34. General quantitative distribution of planktonic foraminifera in waters of the North Pacific Ocean (collections made with metric net) (after Bradshaw, 1959).

1 - 1,000/1,000 m^3; 2 - 100-1,000/1,000^3; 3 - 100/1,000 m^3; 4 - stations studied.

Fig. 35. Overall quantitative distribution of planktonic foraminifera in the southeast Pacific Ocean (in spcm/10,000 m^3) (after Parker, 1960).

1 -<100; 2 - 100-10,000

Distribution of Planktonic

Foraminifera in Bottom Sediments

Information about planktonic foraminifera in Pacific Ocean sediments can be found in many papers, but consists mainly of discussions of foraminiferal classification and their species composition in individual unrelated areas of the bottom. They contain almost no quantitative data or information on the consistent latitudinal range of foraminifera in Pacific Ocean sediments. Data on the presence or absence of foraminifera or individual species were considered in compilation of the charts of distribution of planktonic foraminifera. Such data can be found in Brady's (1884) work, which contains data on the presence of planktonic foraminifera at 181 stations and even on the species composition of foraminifera at 24 stations. Information about planktonic foraminifera exists also for 87 Antarctic stations of the Terra Nova expedition (Heron-Allen, Earland, 1922) and for 132 stations of the NERO expedition located between the islands of Guam and Midway, between Guam and Yokohama, and in the Hawaiian Island region (Flint, 1905; Cushman, 1910-1916).

Some information on the distribution of foraminifera in the northern part of the Ocean (north of 20°N) can be found in works by Cushman, Polskiy, Bandy and others (Anderson, 1963; Bandy, 1953, 1961, 1964; Bagg, 1908; Cushman, Moyer, 1930; Goes, 1896; Hada, 1931; Maruhasi, 1948; Phleger, Ewing, 1962; Polsky, 1959; Waller, Polsky, 1959; Waller, 1960; Zalesny, 1959). The distribution of foraminifera in sediments of the tropical zone of the ocean (20°N-20°S) can be obtained from works by Cushman, Chapman, Todd and others (Cushman, Todd, Post, 1954; Chapman, 1900-1902, 1902; Cushman, 1921, 1924, 1927; Cushman, Kellett, 1929; Goes, 1896; Todd, 1961).

Data on the distribution of foraminifera in southern parts of the ocean, especially south of 20°S, is extremely meager (Cushman, Wickenden, 1929; Sidebottom, 1918; Heron-Allen, Earland, 1924, Parr, 1945, 1950; Parker, 1962). As already mentioned, these works contain no quantitative data. Furthermore, in a number of papers, species identifications are quite doubtful and, sometimes, incorrect. The absence of descriptions and drawings of such forms makes it impossible to verify the classification data. Consequently, even the meager data existing in the literature cannot be fully used.

In addition to the papers listed, there are also a few works that contain quantitative data on the distribution of planktonic foraminifera. For example, they contain data on approximate percentage relationship between species at 24 stations located north of 40°N (Revelle, 1944). There are also data on the correlation of species at a station on the Chatham Rise (Hornibook, 1952), at a station at 26°N, 141°W (Arrhenius, 1963), and on guyots of the Hawaiian Submarine Ridge (Hamilton, 1953). Information about the percentage content of species in the central parts of the ocean (in surface horizons of the core) can be found in reports by Brotzen and Dineson (1959) and Alausson (1960). In addition, there are data on the quantity of planktonic foraminifera relative to weight of sediments in the Bering and Okhotsk Seas, Northwest Pacific Ocean (Belyayeva, 1960; Saidova, 1961), East China and Yellow Seas (Cheng Tsi-Chung, Cheng Sau-Yee, 1960, 1962), and the Antarctic region, Ross, Amundsen, and Bellingshausen Seas (McKnight, 1962; Pflum, 1963).

78/ Materials and Methods of Analysis

The quantity and composition of planktonic foraminifera in recent deposits of the Pacific Ocean were studied using 644 samples collected by RV VITYAZ' and OB'. Locations of the stations are shown in fig. 36. Data from foreign epeditions also were considered (more than 600 stations).

Ten-gram weighted portions of sediments from dried bottom samples usually were used to study planktonic foraminifera. These sediments were filtered through flour mill gauge No. 71, which retains particles larger than 0.05 min. No smaller sized forms were found. When the number of foraminifera in the weighed portion was small (up to several hundred), all specimens were counted; when the number of foraminifera was high, especially in foraminiferal sediments, weighed portions were used. Only whole specimens were counted. If no bottom dredge samples were available, sediment fractions were taken from the upper layer of cores after mechanical analysis (fractions 0.1 mm and 0.1-0.05 mm fractions). The final results are presented as the number of specimens per gram of sediment. The distribution of forms (aggregate quantity and species division) is characterized by the frequency of occurrence (r) expressed in number per unit weight.

Quantitative Distribution of Planktonic Foraminifera by Fractions

To study foraminifera in sediments the number of foraminifera in the 0.01 mm and 0.1-0.05 mm fractions (tabel 7) was counted. Foraminifera occurred very rarely in the fraction less than 0.05 mm. In the fraction

larger than 0.1 mm foraminifera are represented by (a) adult specimens of the asexual reproduction cycle, (b) sexual cycle specimens, which for some reasons did not reproduce sexually in time and reached considerable size, and (c) foraminifera species with large shells.

In the 0.1-0.05 mm fraction, foraminifera are represented by (a) specimens of the reproduction cycle, (b) young specimens of the asexual cycle, (b) specimens of small shelled species, and (d) stunted foraminifera of sexual and asexual reproduction cycles. Because, during the growth of foraminifera generations alternate (sexual and asexual) this alternation changes depending on the environment, the number and correlation of small and large forms change accordingly.

The average arithmetic content of foraminifera (in %) in the fractions was calculated for each zone identified. Between 40° and 20°N, the average content of foraminifera in the >0.1 mm fraction is 74.2%, and in the 0.1-0.05 mm fraction it is 25.8%. In this zone between 20°N and 20°S, the average foraminiferal content in the 0.1 mm fraction is 60.2%, and in the 0.1-0.05 mm fraction, it is 39.8%. In the zone between 20° and 40°S, the average foraminiferal content in the fraction greater than 0.1 mm is 53.0%, while in the 0.1-0.05 mm fraction it is 47%.

Consequently, variations in percentage relationship of foraminifera in the fractions depend on the distribution of fauna in water masses, correlation between small and large size forms in biocoenoses, as well as on depth of burial and the dissolution rate of foraminifera (different degrees of preservation).

By inspection of table 7, it is clearly evident that foraminifera occur in both fractions in all latitudinal zones. And, depending on the factors mentioned above, foraminifera can comprise up to 100% of one of the fractions. From this fact follows the methodologically important conclusion that foraminifera have to be counted in both fractions. Otherwise incorrect conclusions can be formed about both quantitative and qualitative composition of planktonic foraminifera.

79/ Table 7. Di[illegible] Sediment Fractions
(for different la

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Station Number	Wa[illegible] Depth (m)	(%)	Number (Spcm/g)	spcm/g	%	Fraction 0.1-0.05 mm spcm/g	%
			40° - 20°N				
3485	3540	19,4	86,6	86,6	100	0	0
3497	2827	—	4411	4268	96,6	143	3,3
4455	2874	75,96	8777,7	3240,9	37	5536,8	63
4454	3070	78,26	8226,6	5493,1	66,7	2733,5	33,3
3509	4940	—	164,5	0	0	164,5	100
3508	4800	0,41	35,2	0	0	35,2	100
3507	4480	—	16,1	16,1	100	0	0
3516	4150	—	0,3	0,3	100	0	0
3781	2995	—	0,09	0,09	100	0	0
4450	2800	69,18	543	543	100	0	0
3498	2797	47,21	2 995,7	2 895,7	96,6	100	3,3
3586	1768	16,5	3 830,9	2 204,4	60,15	1626,5	39,84
3513	2368	43,2	5 374,1	5 155,9	97,7	118,2	2,2
4451	2549	70,96	1 046,3	1 046,3	100	0	0
4017	2532	72,41	5 183,6	1 673,3	32,18	3510,3	67,7
4452	2895	81,87	10 795,4	10 690,7	99	104,7	1
			20°N - 20°S				
3870	1738	—	32,25	3225	100	0	0
3718	570	87,15	71 982,6	30 726,5	55,15	32 256	44,8
3729	3182	67,62	109,29	109,29	100	0	0
3852	3446	16,08	10	10	100	0	0
3863	4334	—	9406	702	7,5	8704	92,5
3867	4803						58
3903	3825						
3904	2305						2
3908	3530						1
3911	2233						
3918	3110						
3948	4103						
3949	4242	—	0,6	0,6	100	0	0
3953	3836	—	26,9	26,9	100	0	0
3979	1084	24,31	15 399,0	2819,5	18,6	12 549,5	81,4
3986	2190	32,09	5124	3290	64,2	1834	35,8
4269	2980	16,53	1	1	100	0	0
4268	2710	12,8	10 52,0	124,5	11,9	927,5	88,1
5098	4270	—	25,7	25,7	100	0	0
5100	4050	—	17 687,5	5623,5	31,8	12 064,0	68,2
5101	3500	—	122 728,6	16 933,3	13,7	105 795,3	86,2
5102	142	—	1 010,4	533,6	52,7	476,8	47,1
5103	4151	—	614,7	451,3	73,4	163,4	26,6
5104	4235	—	3 997,9	1037,9	26	2960,0	74
5105	3810	—	18 962,0	1788,7	9,5	17 173,3	90,5
5106	2480	—	195 908	511	2,6	26 378,6	13,5
5108	3496	—	131 577,2	28 512	21,7	103 065,2	78,3
5131	3980	—	8771,2	4448,7	50,71	4322,5	49,29
5149	2760	—	20 972,2	549,6	2,7	20 422,6	97,3
5152	4370	—	204,1	204,1	100	0	0
5155	3750	—	3339,0	1347,6	40,4	1991,4	59,6
			20° - 40°S				
3838	3060	21,31	380,3	15,3	4,1	365	95,9
3819	657	—	343,4	323,2	93,1	20,2	5,9
3828	870	—	1104,1	459	41,6	645,1	58,4
3834	4830	—	42,7	42,55	99,7	0,15	0,3
3835	3647	—	164,4	164,4	100	0	0
3836	3546	—	181,8	261,5	67,9	123,0	31,9
3840	1229	—	[illegible]	[illegible]			85,3
3841	159						0
3845	3597						86,6
3846	3757					[illegible]	97,1

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80/ The Aggregate Quantitative Distribution of Planktonic Foraminifera in the Surface Layer of Recent Sediments.

In a total of 664 samples studied, foraminifera were present in 268 samples in different quantities: from less than 1 spcm/g to 212,000 spcm/g of dry natural sediment.

A schematic chart of the quantitative distribution of planktonic foraminifera on the Pacific Ocean bottom (fig. 36) was compiled based on these data. Data from numerous foreign expeditions also were used in its compilation. The isolines on this chart were drawn using a bathymetric chart (The Pacific Ocean, 1963), a sediment chart, and the distribution of calcium carbonate in these sediments (Bezrukov, Lisitsyn, Petelin, Skornyakova, 1961; Bezrukov, Lisitsyn, Romankevich, Skornyakova, 1961).

As is evident from inspection of the chart, planktonic foraminifera are practically absent over extensive regions of the bottom in the northern, central, southeastern, and, in places, southwestern (Tasmanian Sea) parts of the ocean. Maximum (greater than 10,000 spcm/g) and high (from 1,000 to 10,000 spcm/g) concentrations of planktonic foraminifera are restricted to submarine ridges and rises covered with the purest foraminiferal sediments. Low (from <1 to 1,000 spcm/g) concentrations of planktonic foraminifera occur at the bases of underwater ridges and rises and on the bottom of depressions that slightly exceed the "critical" depth below which the calcareous shells of foraminifera are dissolved on the bottom.

In this case, the "critical" depth is defined as the depth below which no complete shells of foraminifera were found. Becasue the dissolution of
81/ $CaCO_3$ shells is not instantaneous, below the "critical" depth is a zone where the sediments consists of foraminiferal fragments and are characterized by high $CaCO_3$ content.

/79/ Table 7. Distribution of Planktonic Foraminifera in Sediment Fractions (for different latitudes).

Station Number	Water Depth (m)	$CaCO_3$ (%)	Total Number (Spcm/g)	Fraction > 0.01 mm spcm/g	Fraction > 0.01 mm %	Fraction 0.1-0.05 mm spcm/g	Fraction 0.1-0.05 mm %
			40° - 20°N				
3485	3540	19,4	86,6	86,6	100	0	0
3497	2827	—	4411	4268	96,6	143	3,3
4456	2874	75,96	8777,7	3240,9	37	5536,8	63
4454	3070	78,26	8226,6	5493,1	66,7	2733,5	33,3
3509	4040	—	164,5	0	0	164,5	100
3508	4800	0,41	35,2	0	0	35,2	100
3507	4460	—	16,1	16,1	100	0	0
3516	4150	—	0,3	0,3	100	0	0
3781	2995	—	0,09	0,09	100	0	0
4450	2800	69,18	543	543	100	0	0
3498	2797	47,21	2 995,7	2 895,7	96,6	100	3,3
3586	1768	16,5	3 830,9	2 304,4	60,15	1526,5	39,84
3513	2368	43,2	5 374,1	5 155,9	97,7	118,2	2,3
4451	2549	70,96	1 046,3	1 046,3	100	0	0
4017	2552	72,41	5 183,6	1 673,3	32,18	3510,3	67,7
4452	2895	81,87	10 795,4	10 690,7	99	104,7	1
			20°N - 20°S				
3870	1738	—	32,25	3225	100	0	0
3718	570	87,15	71 962,6	39 726,5	55,15	32 236	44,8
3729	3182	67,62	109,29	109,29	100	0	0
3852	3446	16,06	10	10	100	0	0
3863	4334	—	9406	702	7,5	8704	92,5
3867	4803	91,77	36 310,2	36 105,4	99,44	204,8	0,56
3903	3825	68,5	21,2	21,2	100	0	0
3904	2305	88,24	25 811,4	6910,22	26,7	18 901,2	73,2
3908	3580	78,53	299,3	200,4	66,9	98,9	33,1
3911	2233	91,78	18 205,6	908,4	5	17 297,2	95
3918	3110	—	647	647	100	0	0
3948	4103	—	6,7	6,7	100	0	0
3949	4242	—	0,6	0,6	100	0	0
3953	3838	—	26,9	26,9	100	0	0
3979	1084	24,31	15 399,0	2819,5	18,6	12 580,5	81,4
3986	2190	32,09	5124	3290	64,2	1834	35,8
4269	2960	16,53	1	1	100	0	0
4268	2710	12,8	10 52,0	124,5	11,9	927,5	88,1
5098	4270	—	25,7	25,7	100	0	0
5100	4050	—	17 687,5	5623,5	31,8	12 064,0	68,2
5101	3500	—	122 728,6	16 933,3	13,7	105 795,3	86,2
5102	142	—	1 010,4	533,6	52,7	476,8	47,1
5103	4151	—	614,7	451,3	73,4	163,4	26,6
5104	4235	—	3 997,9	1037,9	26	2960,0	74
5105	3810	—	18 962,0	1788,7	9,5	17 173,3	90,5
5106	2480	—	195 908	511	2,6	26 378,0	13,5
5108	3496	—	131 577,2	28 512	21,7	103 065,2	78,3
5131	3980	—	8771,2	4448,7	50,71	4322,5	49,29
5148	3780	—	20 972,2	549,6	2,7	20 422,6	97,3
5152	4370	-	204,1	204,1	100	0	0
5155	3750	-	3339,0	1317,6	40,4	1991,4	59,6
			20° - 40°S				
3838	3060	21,31	380,3	15,3	4,1	365	95,9
3819	657	—	343,4	323,2	93,1	20,2	5,9
3828	870	—	1104,1	459	41,6	645,1	58,4
3834	4830	—	42,7	42,55	99,7	0,15	0,3
3835	3647	—	164,4	164,4	100	0	0
3836	3546	—	181,6	281,5	67,9	123,0	31,9
3840	1229	—	42 578,7	6257,4	14,7	36 321,3	85,3
3841	159	—	41,6	41,6	100	0	0
3845	3697	81,51	12 735,1	561,5	4,4	12 173,2	95,6
3846	3757	81,12	28 942,0	838,9	2,9	28 103,1	97,1

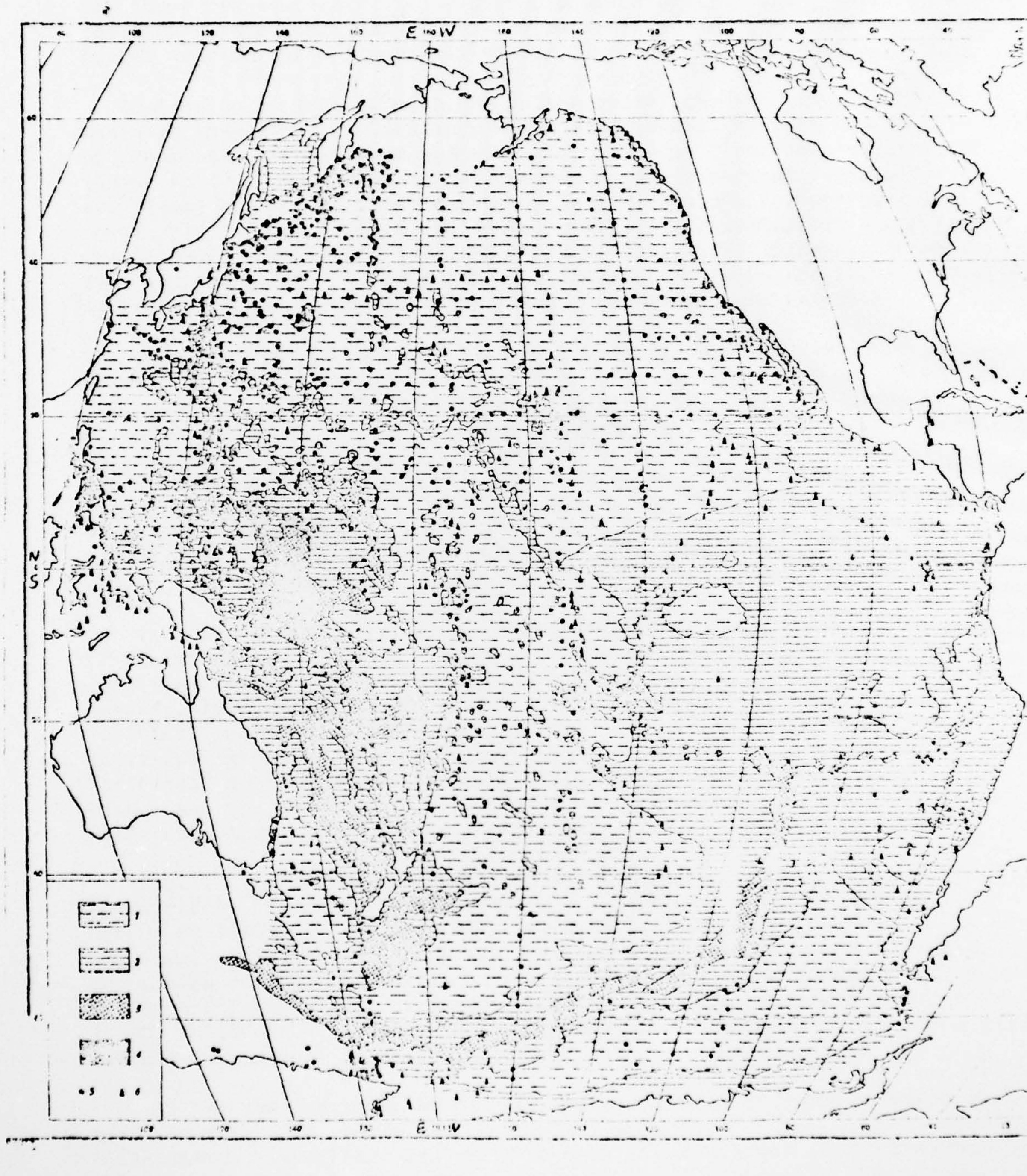

Fig. 36. Quantitative distribution of planktonic foraminifera on the Pacific Ocean bottom (in spcm/g of sediment).

1. absent; 2. 1-1,000; 3. 1,001-10,000; 4. >10,000; 5 VITYAZ' stations at which there are quantitative data; 6. foreign expedition stations for which no quantitative study was done.

For these reasons, there is a 100-200 m discrepancy (rarely more) in the position of the "critical" depth determined from $CaCO_3$ content and from the number (not weight) of unbroken shells of planktonic foraminifera.

Comparison of fig. 36 with the bottom relief chart of the Pacific Ocean makes it possible to establish a clear relationship between the distribution of planktonic foraminifera and submarine relief. Planktonic foraminifers are absent in deep-water oceanic depressions on whose bottoms foraminiferal shells are dissolved. On shelves (depths up to 200 m) and the upper part of the continental slope, in high latitudes, planktonic foraminifera occur rarely and in small numbers (Boltovskoy, 1957; Polsky, 1959; Saidova, 1961a, b). This phenomenon is related to the low content of planktonic foraminifera in waters above the shelves and to dilution by terrigenous material.

Consequently, the overall plan of quantitative distribution of planktonic foraminifera on the ocean bottom differs significantly from the zonal plan of distribution of foraminifera in ocean waters; this fact can easily be observed by comparison of fig. 36 with Bradshaw and Parker's charts (see figs. 23-25). For example, the quantitative maximum of foraminifera in waters of the subarctic region is not reflected in the sediments and is weakly evident in the equatorial region. At the same time, belts of maximum concentrations of planktonic foraminifera on submarine ridges, in places, trend in the meridional direction (Emperor Seamount Chain, East Pacific Ridge), which coincides with the direction of the ridges involved.

In other words, the latitudinal zoning of the quantitative distribution of planktonic foraminifera in ocean waters is complicated and frequently completely masked by the vertical zoning of their distribution in sediments. However, latitudinal zoning is clearly reflected in the variation of "critical" depth from one zone to another as well as in the distribution of individual species; which will be addressed below. In order to determine the "critical" depth of distribution of planktonic foraminiferal shells on the bottom and the regularity of the vertical distribution of these shells at different ocean bottom depths, let us inspect fig. 37 a--e and table 8.

Fig. 37 a--e shows the relationship between distribution of planktonic foraminifera in sediments and water depth (along latitudinal zones). The number of foraminiferal specimens per gram of sediment is plotted along the abscissa, while corresponding depth values were plotted on the ordinate. The tables present information about the frequency of occurrence and average content of foraminifera at 0-200, 200-500, 500-1,000, 1,000-3,000, 3,000-3,500, 3,500-4,000, 4,000-4,500, 4,500-5,000, and greater than 5,000 m depths (within latitudinal zones).

In the zone north of 40°N, 240 samples from 58 to 9,394 m depths were analyzed (fig. 37a, table 8). At 227 stations (at various depths), planktonic foraminifera are either completely absent (202 stations) or are present in quantities smaller than 1 spcm/g of sediment (25 stations). The average foraminiferal content in sediments of this zone is very low and reaches 2,706 spcm/g of sediment only at depths of 1,000-3,050 m; these latter concentrations occurred only on seamounts. Planktonic foraminifera are

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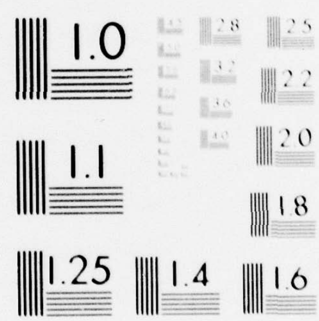

MICROCOPY RESOLUTION TEST CHART
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absent at the same depths on the continental slope. Consequently, it would be more logical to calculate the pertinent arithmetic mean, i.e., the average for the stations over underwater elevations; in this case the foraminiferal content is 59,384 spcm/g. Low frequency of occurrence (at all depths) does
82/ not apply to the foraminiferal distribution everywhere in waters of this zone.

What causes the discrepancy between frequency of occurrence and foraminiferal content in water and in sediments?

On the shelf and continental slope, the low content and often, complete absence of planktonic foraminifera in the sediments frequently is related to dilution by terrigenous material. In the open ocean, on underwater elevations, planktonic foraminifera form pure foraminiferal sediments with a foraminiferal content of up to 76,000 spcm/g of sediments at depths of less than 3,000-3,100 m. At greater depths, foraminifera are absent everywhere due to dissolution on the bottom in cold water unsaturated by $CaCO^3$.

Consequently, in the zone north of 40°N, planktonic foraminifera occur rarely, not because they are absent in the water, but because depths there are greater than the "critical" depth (3,000 m) and, partly, because of dilution by terrigenous material. High concentrations are formed only where the above factors are absent--on underwater ridges and mountains.

In the zone between 40° and 20°N, 153 stations at depths from 216 to 9,736 m were studied. The distribution of the foraminifera by depths is shown in fig. 37b and table 8. At 116 stations, planktonic foraminifera are either absent (100 stations) or occur in quantities lower than 1 spcm/g (116 stations).

The frequency of occurrence of varying numbers of planktonic foraminifera at different depths increases, compared with the preceding zone, and the average content of foraminifera at different depths and the range of occurrence of high foraminiferal content also increase.

The average foraminiferal content in zonal sediments is high in depths of 1,000 to 3,500 m and equals 2,842 and 1,734 specimens. The greatest frequencies of occurrence ($p = 0.70$ and 0.62) are found at the same depths. Below 3,500 m, foraminifera form low concentrations that are related to the solution of $CaCO^3$. Consequently, in this zone, planktonic
86/ foraminifera are characterized by a wider areal and depth distribution of foraminifera that is related to fluctuation in the critical depth around approximately 3,500 m. On the shelf and large areas of the continental slope, planktonic foraminifera are practically absent for the reasons given above.

In the zone between 20°N and 20°S, 155 stations at depths of 25 to 10,917 m were studied. The distribution of planktonic foraminifera at these stations is shown in fig. 37c and in table 8. At 67 stations (mostly greater than 4,500-5,000 m) planktonic foraminifera are lacking. The frequency of occurrence and mean content of planktonic foraminifera significantly increase with depth. Maximum content of planktonic foraminifera occurred above 4,800 m depths with the peak at 500 to 3,500 m depths. At the preceding zone, change in the critical depth is

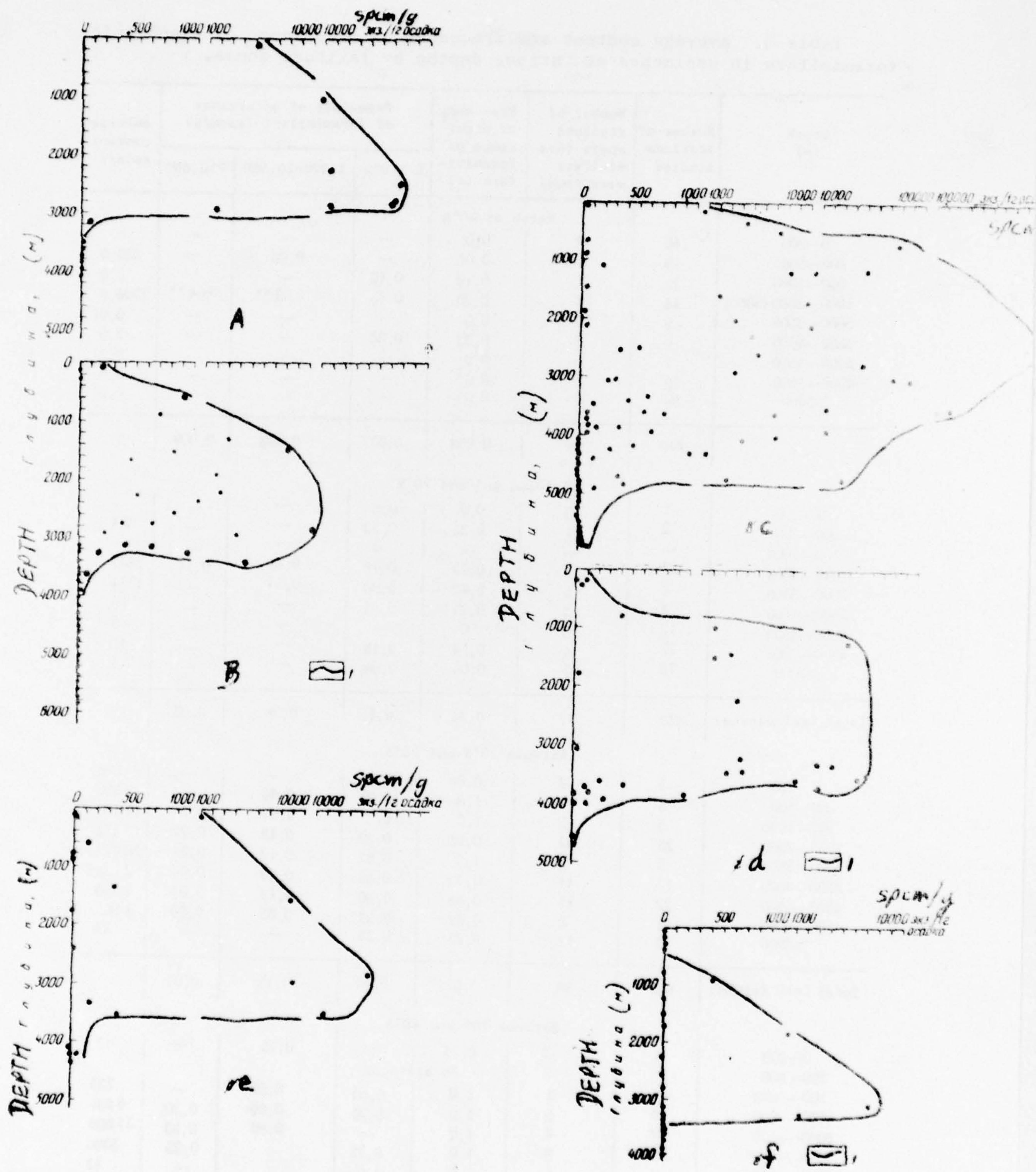

Fig. 37. Relationship of the quantitative distribution of planktonic foraminifera to depth (according to latitudes)

a. north of 40°N; b. 40°-20°N; c. 20°N-20°S; d. 20°-40°S; e. 40°-60°S; f. south of 60°S; 1. Line delineating population density fields.

84/

Table 8. Average content and frequency of occurrence of planktonic foraminifera in sediments at various depths by latitude zones.

Depth (m)	Number of stations studied	Number of stations where foraminifera were found	Frequency of occurrence of foraminifera (r)	Frequency of occurrence of foraminifera (spcm/g)			Average content spcm/g
				1-1,000	1,000-10,000	>10,000	
North of 40°N							
0—200	40	0	0,0	—	—	—	0
200—500	16	1	0,06	—	0,06	—	357,0
500—1000	10	1	0,10	0,10	—	—	0,8
1000—3000 (3050)	44	9	0,20	0,13	0,02 **	0,04 **	2706,0
3000—3500	9	0	0,0	—	—	—	0,01
3500—4000	6	2	0,33	0,33	—	—	2,0
4000—4500	7	0	0,0	—	—	—	0,01
4500—5000	20	0	0,0	—	—	—	0,01
>5000	88	0	0,0	—	—	—	0,01
	240	13	0,054	0,037	0,009	0,009	—
Between 40° and 20°N							
0—200	1	0	0,0	0,0	—	—	—
200—500	3	1	0,33	0,33	—	—	304
500—1000	—	—	—	—	—	—	—
1000—3000	27	19	0,70	0,18	0,41	0,11	2842
3000—3500	8	5	0,62	0,38	0,24	—	1734
3500—4000	8	3	0,37	0,37	—	—	20
4000—4500	12	0	0	—	—	—	0,1
4500—5000	22	4	0,18	0,18	—	—	10
>5000	72	5	0,06	0,06	—	—	0,1
Total (all depths)	153	37	0,24	0,14	0,08	0,02	
Between 20°N and 20°S							
0—200	3	2	0,66	0,66	—	—	606
200—500	3	3	1,0	0,33	0,66	—	2 550
500—1000	5	5	1,0	0,2	0,6	0,2	17 180
1000—3000	23	22	0,95	0,30	0,43	0,22	13 473
3000—3500	8	8	1,0	0,62	0,12	0,25	32 072
3500—4000	15	11	0,73	0,46	0,20	0,06	2 225
4000—4500	22	15	0,68	0,50	0,13	0,04	1 640
4500—5000	21	8	0,37	0,28	0,05	0,05	1 803
>5000	55	14	0,25	0,25	—	—	28
Total (all depths)	155	88	0,57	0,35	0,15	0,07	
Between 20° and 40°S							
0—200	4	3	0,75	—	0,75	—	42
200—500			No stations				
500—1000	2	2	1,0	0,50	0,50	—	723
1000—3000	5	5	1,0	0,20	0,60	0,20	9 931
3000—3500	3	3	1,0	—	0,66	0,33	21 808
3500—4000	8	8	1,0	0,75	—	0,25	5308
4000—4500	1	1	1,0	1,0	—	—	43
4500—5000	1	0	0,0	—	—	—	0
>5000	6	1	0,17	0,17	—	—	30
Total (all depths)	30	23	0,77	0,43	0,20	0,13	

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Depth (m)	Number of stations studied	Number of stations where foraminifera were found	Frequency of occurrence of foraminifera (r)	Frequency of occurrence of foraminifera (spcm/g)			Average content spcm/g
				1-1,000	1,000-10,000	>10,000	
Between 40° and 60°S							
0–200	2	1	0,50	0,50	—	—	2
200–500	1	1	1,0	—	1,0	—	1988,1
500–1000				No stations			
1000–3000	4	4	1,0	0,50	0,25	0,25	17 703
3000–3500				No stations			
3500–4000	1	1	1,0	—	—	1,0	30 392
4000–4500	2	1	0,50	0,50	—	—	55,1
4500–5000				No stations			
>5000				No stations			
Total (all depths)	10	8	0,8	0,4	0,2	0,2	—
South of 60°S							
0–200	1	1	1,0	1,0	—	—	143
200–500	14	10	0,71	0,64	0,07	—	157
500–1000	22	3	0,14	0,14	—	—	16
1000–3000	12	7	0,58	0,50	0,08	—	234
3000–3500	4	3	0,75	0,50	0,25	—	2308
3500–4000	1	0	0	—	—	—	0
4000–4500	1	0	0	—	—	—	0,08
4500–5000				No stations			
>5000				No stations			
Total (all depths)	55 *	24		0,38	0,05	—	—

* Data on the quantity of foraminifera at 44 stations was borrowed from Phlum (1963) and McKnight (1962).
** Stations over seamounts.

responsible for the appearance of additional areas of planktonic foraminifera on the continental slope, submarine elevations, and the ocean bed.

In the zone from 20° to 40°S, 30 stations at depths from 26 to 10,680 m were studied. The range of planktonic foraminifera at these stations is shown in fig. 37d and table 8. The foraminifera were encountered on 23 stations (p = 0.77). Planktonic foraminifera range most widely at depths of 1,000 to 4,000 m where the highest content of foraminifera were noted. The "critical" depth is between 4,000 and 4,500 m.

Ten stations with depths from 114 to 4,418 m were studied in the zone between 40° and 60°S. The distribution of foraminifera is shown in fig. 37e. and table 8. Foraminifera occurred at 8 stations (p = 0.80). The maximum content was at depths of 1,000 to 3,585 m. The critical depth is between 4,000 and 4,500 m. Few stations were studied in the zones between 20° and 40°S and 40° and 60°S. Consequently, conclusions made for these zones, could change.

Fifty-five stations (11 from OB' collections and 44 from McKnight and Pflum's work) were studied in the zone south of 60°S. The distribution of planktonic foraminifera is shown in fig. 37f and table 8. Planktonic foraminifera were found at 24 stations (p = 0.43). They do not form concentrations as high as in the other zones. Maximum contents (up to 8,451 spcm/g of sediment) occurred down to 3,167 m depths. Planktonic foraminifera were not found at depths below 3,300 m.

Based on the above statements, the following conclusions can be drawn. Planktonic foraminifera are either absent or occur in very small quantities on the shelves in all zones. Such a distribution on the shelves is related to low foraminiferal concentrations in waters above the shelves and to dilution by terrigenous sediments. At depths of 200-500 m, the frequency of occurrence and average content (up to several hundred spcm/g) increase. At depths of 500-1,000 m also, the frequency of occurrence and content of foraminifera increase, especially in the tropical zone where they comprise an average of more than 17,000 spcm/g. In all zones, maximum concentrations of planktonic foraminifera were noted below 1,000 m.

Due to the shift to the "critical" depth from 3,000-3,500 m in high latitudes to 4,800 m in low latitudes, the lower limit of distribution of maximum contents of planktonic foraminifera also changes. The areas occupied by globigerina oozes increase correspondingly. Below the "critical" depth the planktonic foraminiferal content does not exceed a few specimens per 50g of sediment. The frequency of occurrence of foraminifera and of large
87/ quantities of foraminifera increase from high to low latitudes. Consequently, the overall quantitative distribution of planktonic foraminifera on the ocean bottom is closely connected with vertical and latitudinal zones.

Distribution of Individual Species

Thirty-three species of planktonic foraminifera were reported in the surface sediment layer of the Pacific Ocean. A list of these is presented below.

Major Family: Globigerinacea, Carpenter, Parker et Jones, 1862.

Family: Globigerinidae Carpenter, Parker et Jones, 1862.

Genus: *Globigerina* d'Orbigny, 1862.

Species: *Globigerina bulloides* d'Orbigny.

Globigerina calida Parker.

Globigerina digitata Brady.

Globigerina falconensis Blow.

Globigerina pachyderma (Ehrenberg).

Globigerina quinqueloba Natland.

Globigerina rubescens Hofker.

Genus: *Globigerinella* Cushman, 1927.

Species: *Globigerinella adamsi* (Bamner et Blow).

Globigerinella aequilateralis (d'Orbigny).

Genus: *Hastigerina* Thomson, 1976.

Species: *Hastigerina pelagica* (d'Orbigny).

Genus: *Globigerinoides* Cushman, 1927.

Species: *Globigerinoides conglobatus* (Brady).

Globigerinoides sacculifer (Brady).

Globigerinoides ruber (d'Orbigny).

Globigerinoides tenellus Parker.

Genus: *Orbulina* d'Orbigny, 1839.

Species: *Orbulina universa* d'Orbigny.

Genus: *Pulleniatina* Cushman, 1927.

Species: *Pulleniatina obliquiloculata* (Parker et Jones).

Genus: *Sphaeroidinella* Cushman, 1927.

Species: *Sphaeroidinella dehiscens* (Parker et Jones).

Family: Globorotaliidae Cushman, 1927.

Genus: *Globorotalia* Cushman, 1927.

Species: *Globorotalia crassaformis* (Galloway et Wissler).

Globorotalia menardii (d'Orbigny).

Globorotalia inflata (d'Orbigny).

Globorotalia hirsuta (d'Orbigny).

Globorotalia pumilio Parker.

Globoratalia scitula (Brady).

Globorotalia truncatulinoides (d'Orbigny).

Globorotalia tumida (Brady).

Genus: *Globoquadrina* Finlay, 1947.

Species: Globoquadrina conglomerata (Schwager).

Globoquadrina dutertrei (d'Orbigny).

Globoquadrina hexagona (Watland).

INTERMEDIATE GENERA:

Genus: Globigerinita Bronnimann, 1951.

Species: Globigerinita glutinata (Egger).

Globigerinita humilis (Brady).

Globigerinita iota Parker.

Globigerinita uvula (Ehrenberg).

Genus: Candeina d'Orbigny, 1839.

Species: Candeina nitida d'Orbigny.

In addition to the listed forms, Pacific Ocean waters also contained the species Hastigerinella rhumbleri and H. difitata. These species have very thin shells and rarely occur in sediments.

Absolute quantities (recalculated per 1g of sediment) and percentage content (relative to total quantity of planktonic formainifera) were calculated for all species at all stations. Based on thse data, charts of quantitative distribution were compiled for all species. Five of these charts are shown in the present work.

Let us turn to description of the distribution of the most typical species on the bottom of the Pacific Ocean. Species are presented below in descending order of their frequency of occurrence in sediments. The selection of species for the tables was based on generic features. Consequently, the sequence of
88/ listing in the table is changed in the textual description of species.

In our data, Globigerina pachyderma (fig. 38, table 9) occurred in sediments at 63 stations in quantities up to 76,000 spcm/g. This species is distributed mainly north of 40°N and south of 40°S, i.e., in the Arctic and boreal, as well as notal and Antarctic zones. This species occurs rarely and in small quantities between 30° and 40°N and between 30° and 40°S. Occurrences of G. pachyderma were reported in Far Eastern seas (Saidova, 1961; Belyayeva, 1960; Anderson, 1963), on the Emperor Seamounts, near the coast of North America, on individual elevations in the Northwest Basin, in the Bonin Islands region, in the Tasman Sea, and in the South Pacific Ocean and on East Pacific Ocean rises. In addition, according to literature sources, it was observed in sediments of the Gulf of California (Bandy), 1961), near Antarctica (Heron-Allen, Earland, 1922), near the southern coast of Australia (Parr, 1950), and on the Chatham Plateau (Hornibrook, 1952).

In waters of the northern part of the ocean, this species was noted north of 40°N. It is confined to subarctic water masses where it comprises from 1 to 20% of foraminiferal fauna. In California Current waters and northeast of Japan (at 8 stations), the species comprises more than 20% of the fauna. The temperature of the surface waters in which G. pachyderma occurs, ranges from 9° to 20°C; higher contents were noted when temperatures were 11° to 17°C (Bradshaw, 1959). This species was not found in southern hemisphere waters. (Parker, 1960), but it probably is present there.

The frequency of occurrence of G. pachyderma in sediments and its average content at various depths in different latitude zones are presented in table 9. As seen from the table, G. pachyderma is a species that is typical of high latitudes. Here it is distributed at all depths (above the "critical" depth), but has not been found at a number of stations due to the considerable content of terrigenous material. Compared to other species, G. pachyderma is distributed most widely in these latitudes. Its maximum concentrations (up to 2,500–6,000 spcm/g of sediment) considerably exceed concentrations of other species.

Globigerina bulloides (see table 9) is widely distributed throughout the entire Pacific Ocean bottom. It occurred at various stations in quantities up to 122,000 spcm/g. This species has been found on elevations in the Northwest Basin, near the Bonin and Japanese islands, off the coast of North America, in the Philippine region, Caroline, Marshall and Solomon islands, on elevations in Northeastern Basin, on the submarine Hawaiian Ridge, on elevations in the Melanesian, North Figi and Central basins, near the Tonga, Kermadec, Marquesas and Tuamotu islands, northwest and northeast of New Zealand, on the New Zealand Plateau, in the Tasman Sea, in the East Pacific, and, in very small quantities, on South Pacific rises, and on rises of the Chile Basin. According to literature data, this species was reported in all 184 CHALLENGER samples collected in different regions of the ocean (Brady, 1884), at more than 100 NERO stations (Flint, 1905; Cushman, 1910–1916), at 19 stations in the Hawaiian Islands region (Bagg, 1908) and west of them on guyots (Hamilton, 1953), near Lord Howe (Heron-Allen, Earland, 1924), Gilbert (Todd, 1961), Marshall (Cushman, Todd, Post, 1954), Philippine (Cushman, 1921). and Samoa (Cushman, 1924) islands, on the north Asiatic shelf (Waller, Polski, 1959), in the Yellow and East China seas (Cheng Tsi-Chung, Cheng Sau-Yee, 1960, 1962), near the west coast of North (Cushman, Moyer, 1930) and South America (Cushman, Kellett, 1929; Cushman, 1927), in the Gulf of California (Bandy, 1953, 1961), near the southern and eastern coasts of Australia and Macquarie Island (Sidebottom, 1918; Parr, 1945, 1950), on the Chatham Rise (Hornibrook, 1952), and near the coast of Antarctica (Heron-Allen, Earland, 1922).

91/ According to Bradshaw's data, this species ranges through all latitudes in North Pacific waters. North of 30°–40°N, in transitional and subarctic water masses, this species occurred everywhere and comprises from 1 to 20%, while in the Aleutian Islands region, it comprises more than 20% of planktonic foraminiferal fauna.

In central and equatorial water masses, G. bulloides occurred in individual small accumulations--spots with this species content of 1 to 20%. Exceptions are the Gulf of California and northeast coast of South America, where the content of this species reaches 20% and more. In the equatorial region, this species occurred in deeper cold waters. In the regions inhabited by G. bulloides, the temperature of the surface water layer ranges from 8° to 31°C; maximum concentrations of this species were found in subarctic and California Current waters in temperatures of 8°-12°C. Based on this phenomenon, this species has been classified as cold-water fauna (Bradshaw, 1959). In southern hemisphere waters, this species occurs south of 40°S in surface water temperatures of 10° to 24°C and salinities of 34°/oo - 35°/oo .

Table 9 shows the species range by latitudes. G. bulloides occurred in all the latitude zones and at practically all depths. Maximum contents of this species were reported at depths of less than 4,000 m between 20°N and 60°S. G. bulloides can be classified as a widely distributed species.

Globorotalia inflata (fig. 39, table 10) occurred in quantities of up to 25,655 spcm/g at 79 stations between 35° and 20°N and between 20°-60°S. In the tropics, between 20°N and 20°S, the species is practically absent. It was found on elevations in the Northwest Basin, near the Japanese and Bonin islands, on the Marcus-Necker submarine mountains, on rises in the Northeast Basin, near the Marquesas Islands, near the east coast of Australia, in the Tasman Sea, in the South Fiji Basin, on Lord Howe, Norfolk and Collville-Lau ridges, on the New Zealand Plateau, Chatham Rise, and in the Chilean Basin. Maximum contents of up to 25,000 spcm/g were noted on the East Pacific and South Pacific rises. In addition, according to literature data, this species is known to exist off the Japanese coast (Uchio, 1952), 1959a, c), in the East China and Yellow seas (Cheng Tsi-Chung, Cheng Sau-Yee, 1960, 1962), on the Asiatic shelf (Waller, Polski, 1959), on seamounts in the North Pacific (Hamilton, 1953), and in the Gulf of California (Bandy, 1953, 1961). In the southern hemisphere, G. inflata was identified off the coasts of Australia and New Zealand, in the Macquarie Islands and Tasmania (Parr, 1945, 1950; Sidebottom, 1918), near Juan-Fernandez (Cushman, Wickenden, 1929), and in the subantarctic region (Heron-Allen, Earland, 1922). On the Chatham Rise, the species comprises up to 65% of the fauna (Hornibrook, 1952).

In North Pacific Ocean waters, this species was reported between 40° and 25°N (in the transitional and central water masses), where it comprises up to more than 10% of foraminiferal fauna; maximum concentrations of this species are confined to waters with temperatures of 21°-22°C. In the southern hemisphere, G. inflata was found in central and subantarctic waters, south of 28°S, in surface waters with temperatures of 10°-23°C and salinities of 34 - 35.7°/oo . G. inflata is a central water species.

In summary, this species ranges mostly between 20° and 40°N and 20°-60°S (table 10). High contents (from several hundred to several thousand spcm/g) and the highest frequency of occurrence, especially at 200-500 to 4,000 m depths, occurred in these regions. In the tropical zone (20°N-20°S) only rare individuals of this species are found. G. inflata is a typical temperate latitude species.

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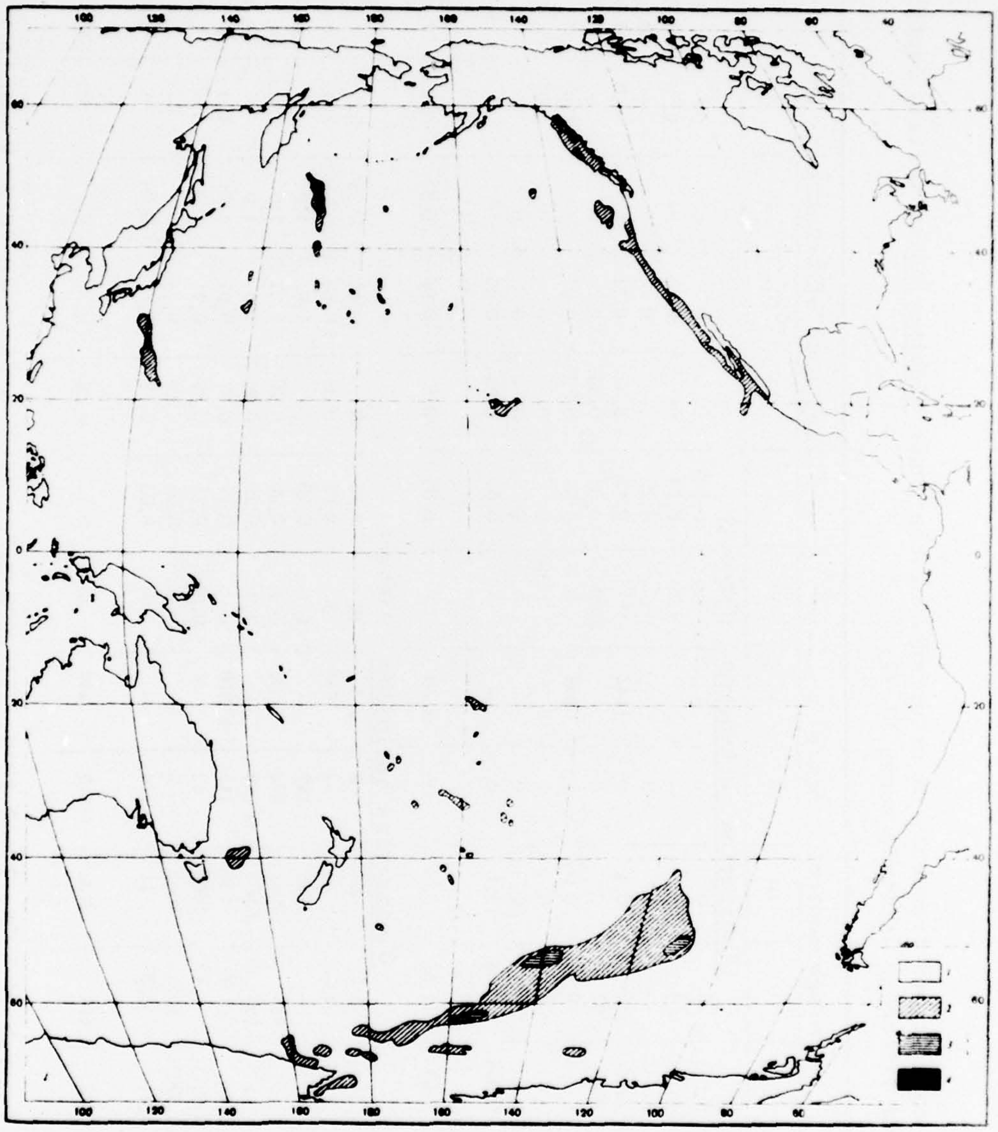

Fig. 38. Distribution of Globigerina pachyderma in Pacific Ocean sediments (in spcm/g of sediment)

1. species absent; 2. 1-1,000; 3. 1,000-10,000; 4. more than 10,000

Table 9. Average content and frequency of occurrence of the genus Globigerina at various depths in the sediments in different latitude zones (I-VI).

Depth (m)	Average content (spcm/g) I	II	III	IV	V	VI	Frequency of occurrence (p) I	II	III	IV	V	VI
			Globigerina pachyderma			(Ehrenberg)						
0—200	0,003	0	0	0	0	79	0,025	0	0	0	0	1,0
200—500	343	0	0	—	0	123	0,19	0	0	—	0	0,78
500—1000	0,8	—	0	0	—	16	0,20	—	0	0	—	0,45
1000—3000	2478	112	0,4	0	1542	191	0,18	0,33	0,22	0	0,25	0,50
3000—3500	1020	91	0	0	—	2300	0,22	0,33	0	0	—	0,75
3500—4000	1,6	0,06	0,06	—	6308	0	0,33	0,12	0,07	—	1,0	0
4000—4500	0	0	0	0	0,16	0,04	0	0	0	0	0,25	1,0
4500—5000	0	0	0	0	—	—	0	0	0	0	—	—
>5000	0,004	0,08	0,1	0	—	—	0,01	0,04	0,05	0	—	—
Average for the zone (all depths)	2,05	11,5	0,1	—	1386	248	0,08	0,1	0,06	0,13	0,33	0,47
			Globigerina bulloides			d'Orbigny						
0—200	0,2	0	464	9	1,2	19	0,15	0	0,66	0,25	0,5	0,7
200—500	3,8	0,5	48	—	945	13	0,25	0,33	0,66	—	1,0	0,42
500—1000	0,03	—	7893	142	—	0,1	0,20	—	1,0	1,0	—	0,13
1000—3000	2	585	2007	579	7536	3,3	0,20	0,70	0,87	1,0	1,0	0,17
3000—3500	41	155	28 868	12 699	—	3,2	0,22	0,66	1,0	1,0	—	0,50
3500—4000	0,4	1,7	190	115	17 920	0	0,17	0,37	0,67	1,0	1,0	0
4000—4500	0,001	1,4	1046	12	16	0,04	0,14	0,09	0,41	1,0	1,0	1,0
4500—5000	0,0001	10,5	1602	0	—	—	0,05	0,19	0,28	0	—	—
>5000	0,01	0,2	11	16	—	—	0,03	0,12	0,27	0,66	—	—
Average for the zone (all depths)	1,86	113	2132	1410	5449	6	0,12	0,28	0,50	0,80	0,90	0,27

* I-north of 40°N; II-40-20°N; III-20°N-20°S; IV-20-40°S; V-40-60°S; VI-south of 60°S.

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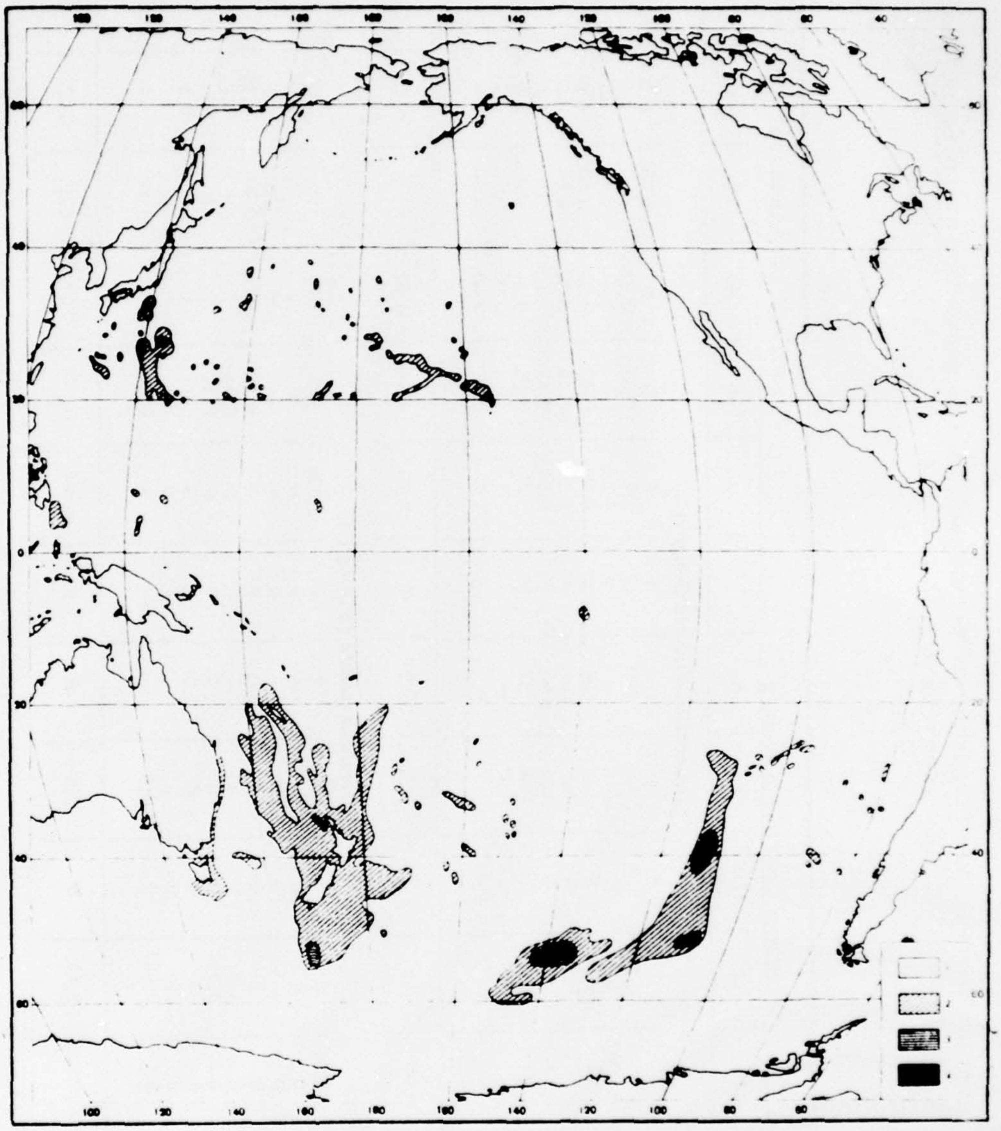

Fig. 39. Distribution of Globorotalia inflata in sediments of the Pacific Ocean (spcm/g of sediment)

1. species is absent; 2. 1-1,000; 3. 1,000-10,000; 4. more than 10,000

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Table 10. Average content and frequency of occurrence of the genus <u>Globorotalia</u> in sediments of different latitude zones (I-VI)

Depth (m)	Average content, spcm/g						Frequency of encounter (p)					
	I*	II	III	IV	V	VI	I	II	III	IV	V	VI
						Globorotalia inflata (d'Orbigny)						
0—200	0	0	0	11	0,9	0	0	0	0	0,50	0,50	0
200—500	0	0,3	7,8	—	809	0	0	0,33	0,33	—	1,0	0
500—1000	0,004	—	24	40,2	—	0	0,10	—	0,4	1,0	—	0
1000—3000	0,02	862	5	750	7629	0	0,09	0,63	0,13	0,60	1,0	0
3000—3500	0,002	392	5	4563	—	0	0,11	0,44	0,25	0,66	—	0
3500—4000	0,25	10	0	137	4086	0	0,17	0,37	0	1,0	1,0	0
4000—4500	0	0,009	3	24	37	0	0	0,09	0,04	1,0	0,5	0
4500—5000	0	0	0,3	0	—	—	0	0	0,05	0	—	—
>5000	0	0,01	0,01	7	—	—	0	0,03	0,02	0,50	—	—
Average for the zone (for all depths)	0,04	173	2	628	3942	0	0,03	0,18	0,07	0,70	0,77	0
						Globorotalia hirsuta (d'Orbigny)						
0—200	0,0005	0	0	0	0	0	0,025	0	0	0	0	0
200—500	0	0	0	—	38	0	0	0	0	—	1,0	0
500—1000	0	—	0	0	—	0	0	—	0	0	—	0
1000—3000	0	2	0	14	240	0	0	0,15	0	0,20	0,25	0
3000—3500	0	1,4	0	0	—	0	0	0,11	0	0	—	0
3500—4000	0	0,1	0	0	0	0	0	0,12	0	0	0	0
4000—4500	0	0	0	0	0,9	0	0	0	0	0	0,5	0
4500—5000	0	0	0	0	—	—	0	0	0	0	—	—
>5000	0	0,007	0	0,9	—	—	0	0,01	0	0,17	—	—
Average for the zone (for all depths)	0,00008	0,45	0	2,3	4,8	0	0,004	0,04	0	0,1	0,33	0

94/ Table 10 (con.)

Depth (m)	Average content, spcm/g						Frequency of encounter (p)					
	I*	II	III	IV	V	VI	I	II	III	IV	V	VI
Globorotalia truncatulinoides (d'Orbigny)												
0—200	0,0005	0	0	0,7	0	0	0,05	0	0	0,25	0	0
200—500	0	27	3	—	136	0	0,05	0,33	0,33	—	1,0	0
500—1000	0	—	34	4,5	—	0	0	—	0,6	1,0	—	0
1000—3000	0,002	236	3	126	479	0	0,07	0,59	0,26	1,0	1,0	0
3000—3500	0	81	11	1684	—	0	0	0,44	0,25	0,66	—	0
3500—4000	0,03	0,3	0,06	1	1648	0	0,17	0,25	0,07	0,25	1,0	0
4000—4500	0	0	0,1	0	0	0	0	0	0,04	0	0	0
4500—5000	0	0	0,1	0	—	—	0	0	0,05	0	—	—
>5000	0,0002	0,0008	0,008	0,9	—	—	0,01	0,03	0,05	0,31	—	—
Average for the zone (for all depths)	0,58	49	2	191	411	0	0,03	0,16	0,12	0,48	0,55	0
Globorotalia menardii (d'Orbigny)												
0—200	0	0	0	1,2	0	0	0	0	0	0,25	0	0
200—500	0	7	164	—	0	0	0	0,33	0,66	—	0	0
500—1000	0	—	488	4,5	—	0	0	—	1,0	1,0	—	0
1000—3000	0	101	198	3	0,9	0	0	0,56	0,78	0,20	0,25	0
3000—3500	0	99	80	10	—	0	0	0,44	1,0	0,66	—	0
3500—4000	0	1,8	59	0,2	0	0	0	0,37	0,80	0,25	0	0
4000—4500	0	0	15	0	0	0	0	0	0,45	0	0	0
4500—5000	0	0	52	0	—	—	0	0	0,28	0	—	—
>5000	0	0,1	0,7	0,0005	—	—	0	0,08	0,18	0,33	—	—
Average for the zone (for all depths)	0	24	65	2	0,34	0	0	0,11	0,49	0,18	0	0

Table 10 (con.)

Depth (m)	Average content, spcm/g						Frequency of encounter (p)					
	I*	II	III	IV	V	VI	I	II	III	IV	V	VI
Globorotalia tumida (Brady)												
0—200	0	0	0,6	0	0	0	0	0	0,33	0	0	0
200—500	0	0	63	—	0	0	0	0	1,0	—	0	0
500—1000	0	—	78	0	—	0	0	—	0,80	0	—	0
1000—3000	0,0001	8	61	2	0	0	0,02	0,44	0,82	0,20	0	0
3000—3500	0	23	13	2	—	0	0	0,33	0,88	0,33	—	0
3500—4000	0	0,6	42	0,08	0	0	0	0,25	0,67	0,12	0	0
4000—4500	0	0,009	171	0	0	0	0	0,08	0,68	0	0	0
4500—5000	0	0	33	0	—	—	0	0	0,33	0	—	—
>5000	0	0,05	3	0,001	—	—	0	0,01	0,18	0,17	—	—
Average for the zone (for all depths)	0,00008	3	47	0,86	0	0	0,004	0,11	0,49	0,16	0	0
Globorotalia crassaformis (Galloway et Wissler)												
0—200	0	0	0	0,2	0	0	0	0	0	0,25	0	0
200—500	0	0	0,1	—	0	0	0	0	0,33	—	0	0
500—1000	0	—	65	3	—	0	0	—	0,80	0,5	—	0
1000—3000	0	23	3	75	0	0	0	0,30	0,30	0,40	0	0
3000—3600	0	0	2	379	—	0	0	0	0,25	0,66	—	0
3500—4000	0,003	0,002	3,6	11	0	0	0,17	0,12	0,20	0,25	0	0
4000—4500	0	0	0	0	0	0	0	0	0	0	0	0
4500—5000	0	0,004	0	0	—	—	0	0,06	0	0	—	—
>5000	0	0	0,03	0	—	—	0	0	0,02	0	—	—
Average for the zone (for all depths)	0,00004	4	2,4	57	0	0	0,004	0,08	0,11	0,23	0	0

* I-north of 40°N; II-40–20°N; III-20°N-20°S; IV-20-40°S; V-40-60°S; VI-south of 60°S.

96/ Globorotalia hirsuta (table 10) occurred in quantities of up to 363 spcm/g in sediments at 14 stations between 20° and 40°N and between 20° and 50°S. This species was noted on elevations in the Northwestern Basin, near the Bonin Is., south of the Hawaiian Islands, and near Tonga, New Guinea, and New Zealand. In addition, according to literature data, this species was found in the Yellow and East China seas (Cheng Tsi-Chung, Cheng Sau-Yee, 1960, 1962), on guyots west of the Hawaiian Islands (Hamilton, 1952), near the Marshall Islands (Cushman, Todd, Post, 1954), and in Bass Strait (Parr, 1945).

In the North Pacific, the species occurs at individual stations in temperate and tropical latitudes, near New Guinea, in the central parts of the ocean, and near the coasts of North and South America. In most cases this species comprises less than 10% of planktonic foraminiferal fauna, and only near the coast of South America does this species comprise more than 10%; G. hirsuta was found in surface waters with temperatures of 16° to 29°C. This species does not form large accumulations and has not been found in southern hemisphere waters. In summary, this species occurred between 40° and 20°N and between 20° and 60°S and was not found in tropical parts of the ocean, and does not form high concentrations anywhere. G. hirsuta is a temperate latitude species.

Globorotalia truncatulinoides (table 10) occurred on the Pacific Ocean bottom at 76 stations in quantities of up to 1,320 spcm/g, but mostly in quantities of several tens and, less frequently, of several hundreds of specimens/g. This species was found between 35°-20°N in the northern hemisphere. Main distribution areas of this species were reported on elevations in the Northwestern Basin, near the Bonin Islands, near the coast of North America, on the Marcus-Necker Ridge, near the Molucca, Marshall, and Caroline Islands, on elevations in the Central Basin in the North Fiji Basin, near the Tonga Islands, in the Tasman Sea, on the New Zealand Plateau, and on the East and South Pacific rises. This species is very rare and occurs in very small quantities in tropical latitudes.

In addition, according to literature data, this species was found in the East China and Yellow seas (Cheng Tsi-Chung, Cheng Sau-Yee, 1960, 1962), near the Japanaese coast (Uchio, 1952), near the Philippine Islands (Cushman, 1921), on sea mounts west of the Hawaiian Islands (Hamilton, 1953), near the North American coast between 32°-40°N and in the Gulf of California (Cushman, Moyer, 1930; Bandy, 1953, 1961), near the Marshall (Cushman, Todd, Post, 1954), Lord Howe (Heron-Allen, Earland, 1924), Juan Fernandez (Cushman, Wickenden, 1929) and Macquarie islands (Parr, 1950), near the coast of Australia (Parr, 1945), and on the Chatham Rise (Hornibrook, 1952).

In the waters of the northern parts of the ocean (Bradshaw, 1959), this species is confined to the central water mass and comprises up to more than 10% of planktonic foraminiferal fauna there. Maximum concentrations were noted in western central water masses on the boundary of the Kuroshio and Oyashio currents. The species occurs less frequently in more northern waters occupying an intermediate position between the central and subarctic water masses. Extremely rare individuals were found in equatorial waters. G. truncatulinioides was found in surface waters with temperatures of 13°-26°C,

and its maximum concentrations of 21-22°C. In the waters of the southern hemisphere, this species comprises, according to Parker, up to 10% of the fauna and was found between 25°-35°S at temperatures of 20.6°-23.5°C and salinities of 34.8°/oo -35.7°/oo. In summary, this species occurred between 40°N and 40°S. Maximum concentrations and highest frequencies of occurrence were between 40° and 20°N and 20° and 40°S. This is a typical temperate zone species.

Globoquadrina dutertrei (table 11) occurred in quantities of up to 829 spcm/g at 130 stations. In the north, the species extends up to 30°N in
98/ the west and up to 20°N in the east; while in the south, it extends up to 50°S. G. eggeri was noted on elevations in the Northwestern and Northeastern basins, south of the Gulf of California and Hawaiian Islands, near the Bonin Islands, north and south of the Caroline Islands, north of the Moluccas, north and south of New Guinea, near the Solomon Islands, in the Melanesian, North Fiji, South Fiji and Central basins, near the Phoenix, Samoa, and Tonga islands, north and south of New Zealand, near the Tuamotu and Marquesas islands, in the Chile Basin, and on the East Pacific Rise. G. eggeri is a temperate and tropical latitude species with maximum concentrations between 20°N and 20°S. According to literature data, this species was found in sediments of the Hawaiian Archipelago (Bagg, 1908), near Lord Howe (Heron-Allen, Earland, 1924) and Gilbert islands (Todd, 1961), in the Funafuti Atoll (Chapman, 1900-1902, 1902), on guyots west of the Hawaiian Islands (Hamilton, 1953), near the Philippine Islands (Cushman, 1921), in the Yellow and East China seas (Cheng Tsi-Chung, Cheng Sau-Yee, 1960, 1962), on the northern Asiatic shelf (Waller, Polski, 1959), on the Chatham Rise (Hornibrook, 1952), near the east coast of Australia (Parr, 1950), and in the Gulf of California (Bandy, 1953, 1961).

In Pacific Ocean waters, this species occurs between 42°N and 35°S in water temperatures of 8° to 32°C. Maximum concentrations were noted in transitional water, in the California and Peru current regions, in areas of intermixing of the warm Kuroshio and cold Oyashio waters, and northeast of Japan. In the regions listed, this species comprises more than 20% of the foraminiferal fauna, while in equatorial and central waters this species comprises less than 20% (Bradshaw, 1959). In the southern hemisphere, the species is very numerous near the South American coast and in equatorial, south-central, and transitional (subantarctic) waters in surface waters with salinities of 34-36.4°/oo and temperatures of 16°-27°C (Parker, 1960). G eggeri is a typical species in latitudes 40°N to 40°S. Maximum concentrations are confined to depths of 500-3,500 m. This species is a warm-water type and predominates in the tropical zone.

Globorotalia menardii (table 10, fig. 40) occurred in quantities of up to 1,752 spcm/g at 112 stations. Its northern range boundary follows latitudes 30°N in the west and 20°N in the east, while the southern boundary follows 20°S; individual occurrences are reported between 20° and 40°S. This species was found on elevations in the Northwestern, Northeastern, and Central basins, near the Bonin Islands, south of the Hawaiian Islands, near the North American coast, south of the Gulf of California, north of the Moluccas and New Guinea, in the region of the Caroline, Marshall and Marquesas islands, in the North Fiji and Melanesian basins, near the Phoenix, Gilbert, Samoa, Tuamotu, Tonga and Kermadex islands, at one station south of New Zealand, and in the northern end of the East Pacific Rise. G. menardii is a typical species in latitudes 20°N to 20°S.

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Table 11. Average content and frequency of occurrence of the genus Globoquadrina in sediments of different latitude zones (I-VI).

Depth (m)	Average content, spcm/g						Frequency of encounter (p)					
	I*	II	III	IV	V	VI	I	II	III	IV	V	VI
						Globoquadrina dutertrei (d'Orbigny)						
0—200	0,0005	0	1,1	0.2	0	0	0,025	0	0,33	0,25	0	0
200—500	0	5,7	118	—	15	0	0	0,33	1,0	—	1,0	0
500—1000	0	—	2100	0	—	0	0	—	1,0	—	—	0
1000—3000	0,015	182	823	20	0	0	0,07	0,08	0,91	0,60	0	0
3000—3500	0,002	40	72	783	—	0,15	0,11	0,55	0,75	1,0	—	0,25
3500—4000	0,01	0,08	28	11	215	0	0,17	0,12	0,53	0,62	1,0	0
4000—4500	0	0	111	0	0,2	0	0	0	0,50	0	0,5	0
4500—5000	0	0	8	0	—	—	0	0	0,33	0	—	—
>5000	0,001	0,01	0,3	0	—	—	0,02	0,05	0,13	0	—	—
Average for the zone (for all depths)	0,03	43	110	84	26		0,03	0,18	0,47	0,43	0,33	0,15
						Globoquadrina conglomerata (Schwager)						
0—200	0	0	0	0	0	0	0	0	0	0	0	0
200—500	0	0	0,8	—	0	0	0	0	0,08	—	0	0
500—1000	0	—	7	0	0	0	0	—	0,40	0	—	0
1000—3000	0	0	15	1	0	0	0	0	0,43	0,20	0	0
3000—3500	0	8	11	3	0	0	0	0,11	0,62	0,33	—	0
3500—4000	0	0	28	0	0	0	0	0	0,40	0	0	0
4000—4500	0	0	33	0	0	0	0	0	0,45	0	0	0
4500—5000	0	0	1	0	—	—	0	0	0,05	0	—	—
>5000	0	0	0,01	0	—	—	0	0	0,04	0	—	—
Average for the zone (for all depths)	0	0,40	11	0,04	0	0	0	0,008	0,25	0,08	0	0

* I-north of 40°N; II-40-20°N; III-20°N-20°S; IV-20-40°S1 V-40-60°S; VI-south of 60°S.

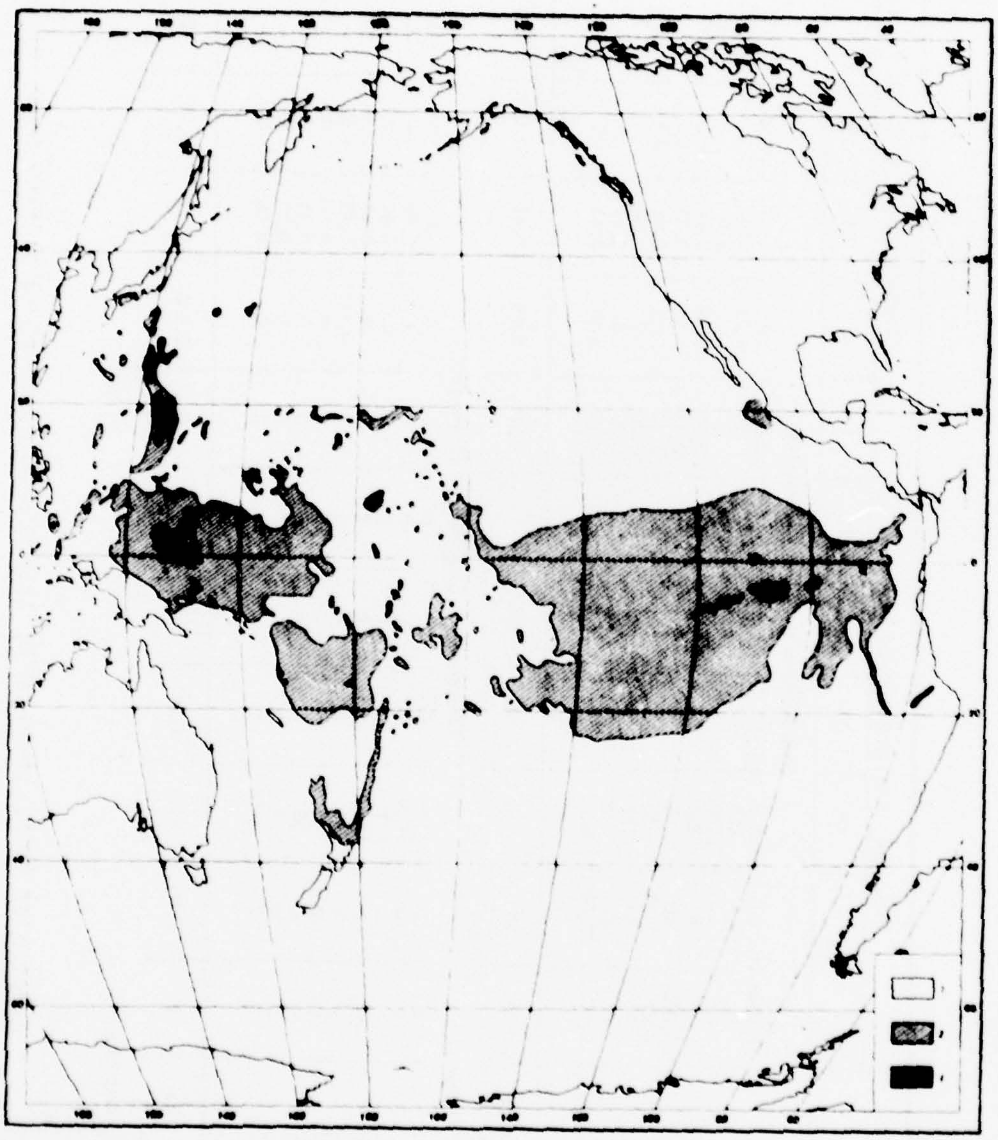


Fig. 40. Distribution of Globorotalia menardii in Pacific Ocean sediments (in specm/g of sediment).

1. species is absent; 2. 1-1,000; 3. 1,000-10,000.

Table 12. Mean content and frequency of occurrence of the genus Globigerinoides in sediments by depths and in different latitude zones (I-VI).

Depth (m)	Average content, spcm/g						Frequency of encounter (p)					
	I*	II	III	IV	V	VI	I	II	III	IV	V	VI
Globigerinoides conglobatus (Brady)												
0–200	0,0005	0	0,6	1,4	0	0	0,02	0	0,33	0,25	0	0
200–500	0	0	163	—	0	0	0	0	1,0	—	0	0
500–1000	0	—	280	6,5	—	0	0	—	1,0	1,0	—	0
1000–3000	0,001	76	183	58	0	0	0,07	0,41	0,91	0,80	0	0
3000–3500	0	119	172	505	—	0	0	0,22	1,0	1,0	—	0
3500–4000	0	0,9	64	6	0	0	0	0,37	0,67	0,50	0	0
4000–4500	0	0	10	0	0	0	0	0	0,38	0	0	0
4500–5000	0	0	1	0	—	—	0	0	0,19	0	—	—
>5000	0	0	0,2	1,6	—	—	0	0	0,21	0,33	—	—
Average for the zone (for all depths)	0,0004	20	526	61	0	0	0,02	0,10	0,47	0,50	0	0
Globigerinoides sacculifer (Brady)												
0–200	0,001	0	16,4	0	0	0	0,025	0	0,33	0	0	0
200–500	0	14,6	433	—	0	0	0	0,33	1,0	—	0	0
500–1000	0	—	1180	31	—	0	0	—	1,0	1,0	—	0
1000–3000	0,001	197	399	316	0	0	0,02	0,48	0,86	0,80	0	0
3000–3500	0	59	419	91	—	0	0	0,44	1,0	0,86	—	0
3500–4000	0,006	0	102	1,2	0	0	0,17	0	0,67	0,50	0	0
4000–4500	0	0	39	0	0	0	0	0	0,45	0	0	0
4500–5000	0	0,0004	5	0	—	—	0	0,05	0,12	0	—	—
>5000	0,001	0	0,4	0,6	—	—	0,01	0	0,21	0,33	—	—
Average for the zone (for all depths)	0,001	38	142	66	0	0	0,01	0,10	0,17	0,33	0	0
Globigerinoides ruber (d'Orbigny)												
0–200	0	0	118	24	0	0	0	0	0,66	0,50	0	0
200–500	0	23	605	—	0	0	0	0,33	1,0	—	0	0
500–1000	0	—	3108	75	—	0	0	—	1,0	1,0	—	0
1000–3000	0,005	284	457	474	0	0	0,09	0,52	0,88	0,80	0	0
3000–3500	0	111	2022	671	—	0	0	0,22	0,88	1,0	—	0
3500–4000	0	0,4	320	63	0	0	0	0,25	0,53	0,75	0	0
4000–4500	0	0	11	6	0	0	0	0	0,23	1,0	0	0
4500–5000	0	0	88	0	—	—	0	0	0,19	0	—	—
>5000	0,0008	0,04	0,2	4	—	—	0,02	0,04	0,10	0,17	—	—
Average for the zone (for all depths)	0,001	54	304	173	0	0	0,02	0,11	0,43	0,63	0	0

* I-north of 40°N; II-40-20°N; III-20°N-20°S; IV-20-40°S; V-40-60°S; VI-south of 60°S.

Table 13. Mean content and frequency of occurrence of Globigerinella aequilateralis (d'Orbigny) in sediments of different latitude zones (I-VI)

Depth (m)	Average content, spcm/g						Frequency of encounter (p)					
	I*	II	III	IV	V	VI	I	II	III	IV	V	VI
0—200	0,0005	0	1,1	0	0	0	0,025	0	0,33	0	0	0
200—500	0	1	158	—	0	0	0	0,33	1,0	—	0	0
500—1000	0	—	498	2	—	0	0	—	1,0	1,0	—	0
1000—3000	0,001	38	117	100	0	0	0,04	0,37	0,87	0,60	0	0
3000—3500	0	5	142	70	—	0	0	0,22	1,0	1,0	—	0
3500—4000	0	0	44	0	0	0	0	0	0,53	0	0	0
4000—4500	0	0	27	0	0	0	0	0	0,36	0	0	0
4500—5000	0	0	0,8	0	—	—	0	0	0,14	0	—	—
>5000	0,0002	0,0003	0,1	0	—	—	0,01	0,01	0,04	0	—	—
Average for the zone (for all depths)	0,0006	6,7	53	24	0	0	0,01	0,1	0,37	0,38	0	0

I-north of 40°N; II-40-20°N; III-20°N-20°S; IV-20-40°S; V-40-60°S; VI-south of 60°S.

According to literature data, this species occurs on guyots west of the Hawaiian Islands (Hamilton, 1953), near the Marshall Islands (Cushman, Todd, Post, 1954), at 104 stations in the Philippine Archipelago (Cushman, 1921), in the Funafuti Atoll region (Chapman, 1900-1902), in the Yellow and East China seas (Cheng Tsi-Chung, Cheng Sau-Yee, 1960, 1962), near the North American Coast (Cushman, Moyer, 1930), on the Asiatic shelf, south of Korea (Waller, Polski, 1959), in Tokyo Bay (Uchio, 1952), near the shores of of Australia (Parr, 1950),

In Pacific waters, G. menardii has been reported south of 40°N in the west and south of 20°N in the east, and in the southern hemisphere--to 30°S
102/ in equatorial and central waters having temperatures of 16° to 32°C. The highest concentrations were in the equatorial region in temperatures of 24°-32°C; here G. menardii comprised up to 20% of the foraminiferal fauna (Bradshaw, 1959). In the southern part of the ocean the species occurred in equatorial and south-central water masses in temperatures of 17.7°-27.3°C and in salinities of 34-35.9°/oo (Parker, 1960).

In summary, G. menardii was found only between 40°N and 40°S; maximum accumulations and the species ranges generally between 20°S and 20°N at depths of 200 to 4,000 m. G. menardii is a typical tropical species.

Globigerinoides conglobatus (Table 12) was found in quantities of up to 1,440 spcm/g. The northern range boundary of the species in the western part of the ocean follows 30°N, while in the central and eastern parts--20°N; the southern boundary--20°N. Rarely, low contents were reported between 20-40°S. The species occurred on elevations in the Northwestern, Northeastern and Central basins, near the Nanpo Islands north of the Moluccas, north and south of the Carolines and New Guinea, in the Melanesian and North Fiji basins, near the Gilbert, Tonga, Kermadec, Samoa, Phoenix, Tokelau, Marshall, Marquesas and Tuamotu islands, in the Chile Basin, and on the northern end of the East Pacific Rise. In addition, low contents of this species were observed south of Hawaii, and near the North American coast, south of the Gulf of California. G. conglobatus ranges through northern temperate and, especially, in tropical
102/ and southern temperate latitudes.

In addition, according to literature data, G. conglobatus was found in sediments of the Hawaiian Archipelago (Bagg, 1908), near the Philippine (Cushman, 1921, Marshall (Cushman, Todd, Post, 1954), Gilbert (Todd, 1961) and Samoan islands (Cushman, 1924), in Funafuti Atoll (Chapman, 1900-1902), on guyots west of the Hawaiian Islands (Hamilton, 1953), in the Gulf of California (Bandy, 1961), in the Yellow and East China seas (Cheng Tsi-Chung, Cheng Sau-Yee, 1960, 1962), and near the southern and eastern coasts of Australia (Parr, 1950).

In waters of the North Pacific Ocean, G. conglobatus is known south to 40°-30° in the western part of the ocean and south of 20° in the eastern part. This warm-water species occurs in surface water temperatures of 16-32°C. In central water masses, the species content does not exceed 10%, and maximum contents (>10%) were noted in equatorial waters (Bradshaw, 1959). In the southern hemisphere, this species was found up to 35°S in water temperatures of 17.7-27.3°C and salinities of 34.7-36.3°/oo (Parker, 1960).

In summary, this species is absent north of 40°N and south of 40°S. The greatest contents and frequencies of occurrence were confined to 200 to 4,000 m. depths between 40° and 20° of both hemispheres, especially between 20°N and 20°S.

Globigerinoides sacculifer (table 12) occurred in quantities of up to 4,308 spcm/g at 120 stations between 20°N in the east and 30°N in the west and south to 30°-40°S. This species was found on elevations in the Northwest and Eastern basins, south of the Gulf of California, near the Bonin Islands, south of the Hawaiian Islands and New Guinea, in the region of the Molucca, Marquesas, Phoenix, Samoa, Tonga, Marshall and Tuamotu islands, in the Melanesian and North and South Fiji basins, north and south of New Zealand, and on the northern end of the East Pacific Rise. G. sacculifer, as well as G. conglobatus are most characteristic of latitudes 20°N to 40°S.

According to literature data, this species occurred in sediments of the Philippine Archipelago (Cushman, 1921), near the Hawaiian Islands (Bagg, 1908), near Samoa (Cushman, 1924), the Gilbert (Todd, 1961) and Marshall Islands (Cushman, Todd, Post, 1954), in the East China and Yellow seas
103/ (Cheng Tsi-Chung, Cheng Sau-Yee, 1960, 1962), in the Gulf of California (Bandy, 1961), in the Funafuti Atoll region (Chapman, 1900-1902), on guyots west of the Hawaiian Islands, (Hamilton, 1953), and near the west coast of North Anerica (Cushman, Moyer, 1930) and the east coast of Australia (Parr, 1950).

In the Pacific waters, this species occurred from 30-40°N in the west and 20°N in the east to 30°-35°S. This warm-water species was found in central (up to 10%) and equatorial waters (10%) with temperatures of 16° to 32°C. Its maximum concentrations and role in the faunal content increase to 80-97% in equatorial waters with temperatures of 24°-29°C. In southern hemisphere waters, the species was found in water with temperatures of 17.7°-27.3°C and salinities of 34.7-36.3°/oo.

G. sacculifer, a typical tropical species, ranges between 40°N and 40°S with minimum concentrations and occurs least frequently between 20°N and 20°S.

Globoquadrina conglomerata (table 11) was found on the Pacific Ocean bottom in quantities of 1 to 475 spcm in 44 samples. This species occurs quite rarely and in small numbers, and its main ranges are confined to 10°N-20°S. North of 10°N, 76 spcm/g of this species occurred at one station. South of 20°S, this species was found near the east coast of Australia and at 30°S on the East Pacific Rise. One should also mention the rare occurrence of this species in waters of the Philippine Archipelago (Cushman, 1921), near the Marshall Islands (Cushman, Todd, Post, 1954), in San Pedro Bay, California (Bandy, 1953), near the North American coast north of 7°N (Cushman, Moyer, 1930), near the west coast of South America (Cushman, Kellet, 1929), near the Australian Coast (Parr, 1950), and near Juan Fernandez Island (Cushman, Wickenden, 1929).

In the Pacific Ocean, G. conglomerata occurred only in the equatorial zone in waters with temperatures of 22°-31°C; maximum concentrations (up to 30% of the fauna) occurred in water temperatures of 26°-28°C. In summary, G. conglomerata ranged only between 20°N and 20°S and is a typical tropical species.

Globigerinella aequilateralis (fig. 41, table 13) occurred in 90 samples on the Pacific Ocean bottom in quantities up to 1,186 spcm. In the northern hemisphere, this species occurred up to 34°N in the west and to 20°N in the east. The southern distribution boundary of this species follows 40°S. G. aequilateralis was found near the Mariana, Nanpo and Bonin islands, on Kapingamarangi submarine ridge, near the Gilbert, Marquesas and Tuamotu islands, in the North Guinea Basin, on the Colville-Lau Ridge, and on the Marcus-Necker and East Pacific rises. According to literature data, G. aequilateralis also occurred in sediments of the Hawaiian Archipelago (Bagg, 1908), on seamounts west of Hawaii (Hamilton, 1953), between Guam and Yokohama, near the Galapagos Islands (Flint, 1905), near the Marshall Islands (Cushman, Todd, Post, 1954), in the Gulf of California (Bandy, 1953, 1961), near the coast of the Japanese islands (Uchio, 1952), in the Yellow and East China seas (Cheng Tsi-Chung, Cheng Sau-Yee, 1960, 1962), at 72 stations in the Philippine Islands region (Cushman, 1921), near Samoa (Cushman, 1924) and the Gilbert Islands (Todd, 1961), near the coast of western North America (Cushman, Moyer, 1930), in the Funafuti Atoll region (Chapman, 1900-1902), near the south and east coasts of Australia (Parr, 1950), and off the coast of South America (Cushman, Kellett, 1929). In Pacific Ocean waters, the range boundaries of this species follow 30°-40°N and 40°S. This species is confined to central and equatorial water masses with temperatures of 17° to 32°C, while maximum contents (>20%) were noted in equatorial
104/ water having temperatures of 24°-30°C.

In summary, G. aequilateralis ranged between 40°N and 40°S; the main range and high species contents were reported in the zone 20°N to 20°S.

Pulleniatina obliquiloculata (fig. 42, table 14) was found on the Pacific Ocean bottom in quantities of 1 to 4,420 spcm/g in 114 samples obtained between 34°N in the west, 20°N in the east, and 30°S. Rarely, small quantities were found north of 20°N on rises in the Northwest Basin and near the Bonin, Nanpo and Osumi islands; the other distribution areas of the species are farther south: northwest of New Guinea, on Eauripic Rise, near Farauna, in the Melanesian and East Caroline basins, in the Coral Sea, on elevations of the Central Basin, near the Fiji, Toksau (Tokelau?), Samoa and Tonga islands, on the Colville-Lau Ridge, east of New Zealand, in the Northeast Basin, and near Christmas and Marquesas islands. In addition, P. obliquiloculata was found at 19 stations near the Hawaiian Islands (Bagg, 1908), at 75 stations between Guam and Yokahama (Flint, 1905), at 5 stations in the Philippine Islands region (Cushman, 1921), in the Funafuti Atoll region (Chapman, 1900-1902), near the Marshall Islands (Cushman, Todd, Post, 1954), in the Gulf of California (Bandy, 1953, 1961) where this species comprises approximately 1% of planktonic foraminifera, in the Yellow and East China seas (Cheng Tsi-Chung, Cheng Sau-Yee, 1960-1962), near the Gilbert Islands (Todd, 1961), on a shelf south of Korea (waller, Polsky, 1959), and near the eastern and southeastern coast of Australia (Parr, 1950). This species is most typical in latitudes 20°N to 20°S.

This species ranges most widely in Pacific Ocean waters south of 40°N in the western part of the ocean and south of 20°N in the east where (water) temperatures are 16°-32°C (Equatorial and West-central water masses). Maximum concentrations (1,000 spcm/1,000 m of water) were found in equatorial water masses south of the Hawaiian Islands in (water) temperatures of 27°-30°C (parker, 1960; Bradshaw, 1959).

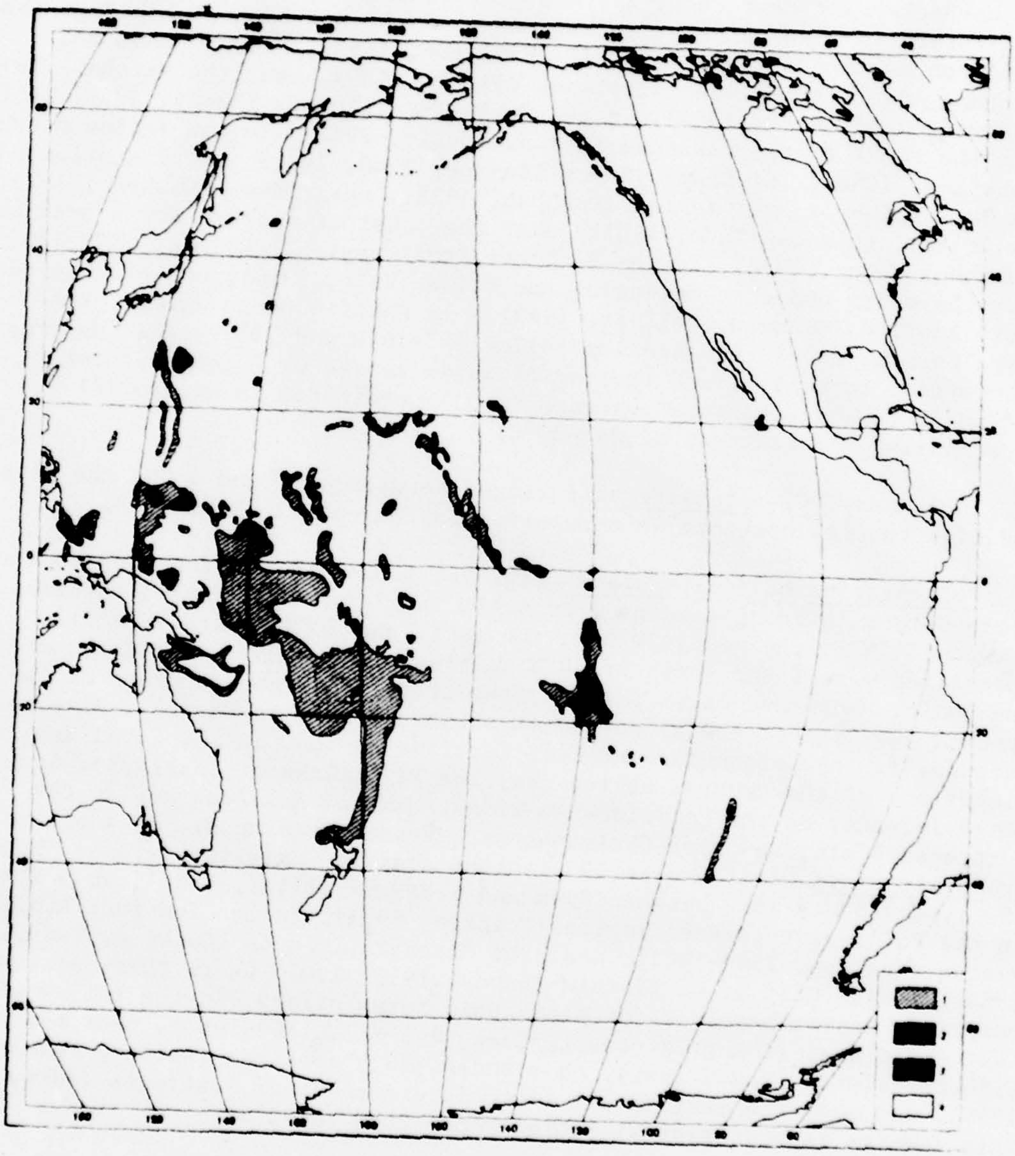


Fig. 41. Distribution of Globigerinella aequilateralis in sediments of the Pacific Ocean (in spcm/g of sediments)

1. species absent; 2. 1-1,000; 3. 1,000-10,000; 4. >10,000.

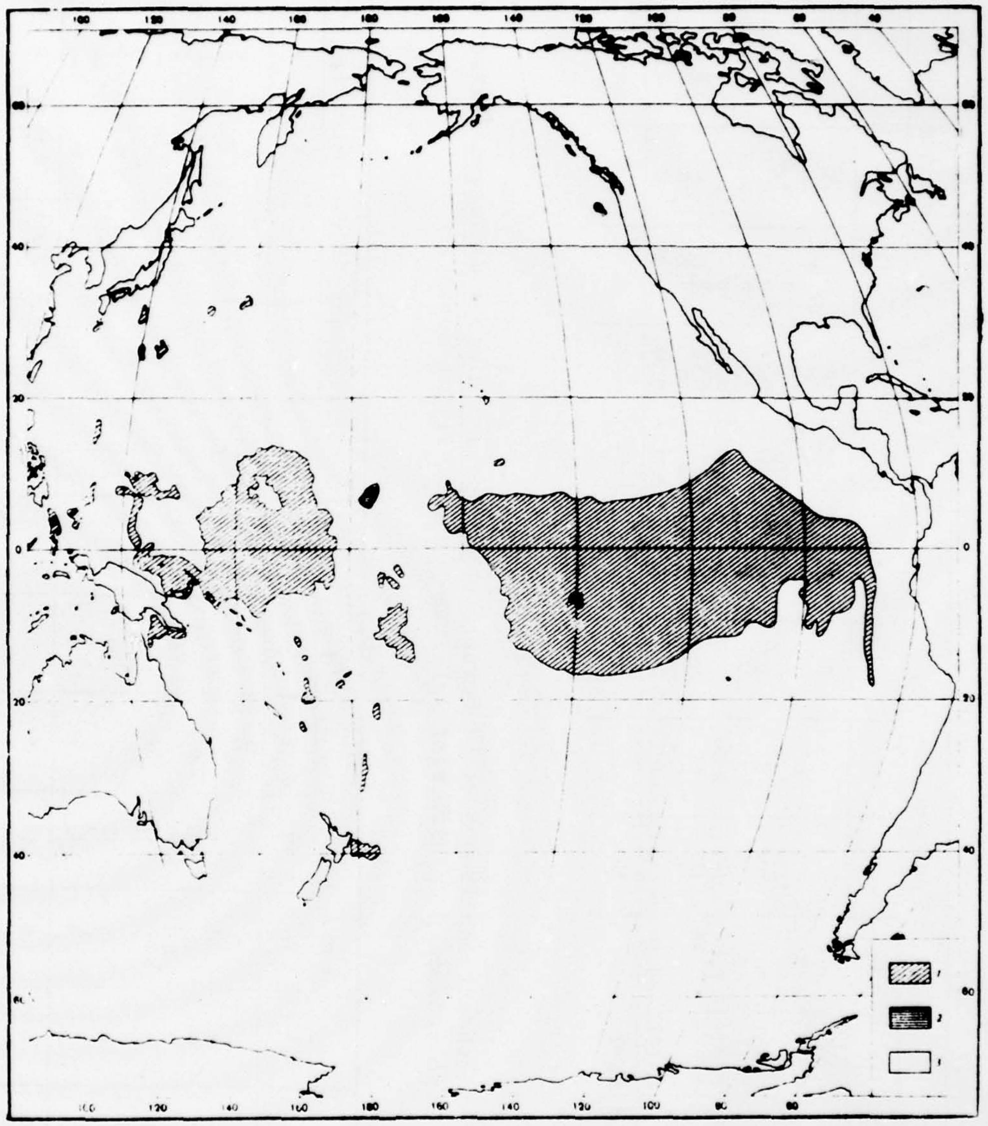


Fig. 42. Distribution of Pulleniatina obliquiloculata in sediments of the Pacific Ocean (in spcm/g of sediments)

1. species absent; 2. 1-1,000; 3. 1,000-10,000.

Table 14. Average content and frequency of occurrence of Pulleniatina obliquiloculata (Parker et Jones) in sediments in various latitude zones (I-VI) by depths.

Depth (m)	Average content, spcm/g						Frequency of encounter (p)					
	I*	II	III	IV	V	VI	I	II	III	IV	V	VI
0—200	0,001	0	0	0	0	0	0,05	0	0	0	0	0
200—500	0,001	0	361	—	0	0	0,06	0	1,0	—	0	0
500—1000	0	—	1238	1,5	—	0	0	—	0,8	0,50	—	0
1000—3000	0,008	30	194	2	0	0	0,11	0,41	0,91	0,20	0	0
3000—3500	0	7	102	2	—	0	0	0,33	0,88	0,33	—	0
3500—4000	0,003	0,1	167	0,5	0	0	0,17	0,12	0,73	0,12	0	0
4000—4500	0	0,009	157	0	0	0	0	0,09	0,64	0	0	0
4500—5000	0	0	14	0	—	—	0	0	0,28	0	—	—
>5000	0,0007	0,09	3	0	—	—	0,01	0,04	0,16	0	—	—
Average for the zone (for all depths)	0,002	6	120	1	0	0	0,04	0,12	0,50	0,6	0	0

Table 15. Average content and frequency of occurrence of Sphaeroidinella dehiscens (Parker et Jones) in sediments in different latitude zones (I-VI) at depths.

Depth (m)	Average content, spcm/g						Frequency of encounter (p)					
	I*	II	III	IV	V	IV	I	II	III	IV	V	VI
0—200	+	0	0	0	0	0	+	0	0	0	0	0
200—500	0	0,5	86	—	0	0	0	0,33	1,0	—	0	0
500—1000	0	—	20	0,7	—	0	0	—	1,0	0,5	—	0
1000—3000	0	5,7	56	0	0	0	0	0,33	0,74	—	0	0
3000—3500	0	6	17	1	—	0	0	0,44	1,0	0,33	—	0
3500—4000	0	3	17	0,02	0	0	0	0,25	0,73	0,12	0	0
4000—4500	0	0	12	0	0	0	0	0	0,54	0	0	0
4500—5000	0	0	1,4	0	—	—	0	0	0,24	0	—	—
>5000	0	0,1	0,4	0	—	—	0	0,01	0,13	0	—	—
Average for the zone (for all depths)	0	1,6	16	0,14	0	0	0	0,12	0,44	0,10	0	0

* I-north of 40°N; II-40-20°N; III-20°N-20°S; IV-20-40°S; V-40-60°S; VI-south of 60°S

In summary, P. obliquiloculata is a typical tropical species, even though individuals were encountered north of 20°N and south of 20°S.

Globigerinoides ruber (see table 12) occurred at 118 stations in quantities of up to 14,344 spcm/g. The northern boundary of this species follows 34°N in the west and 20°N in the east, while the southern follows 40°S. We found the species on elevations of the Northwest Basin, near the Nanpo and Bonin islands, north of the Mariana Islands, in the East Caroline Basin, north of the Moluccas, south of New Guinea, near the Marshall Islands, in the North-Fiji and South Fiji basins, northwest and northeast of New Zealand, near the east coast of Australia, in the Tasman Sea, on the Tonga Ridge, near the Samoa, Tuamotu, and Marquesas islands, on elevations in the Central Basin, and on the East Pacific Ridge.

In addition, this species was found on seamounts west of Hawaii (Hamilton, 1953), around the Hawaiian Islands (Bagg, 1908), at 8 stations in the Philippine Archipelago (Cushman, 1921), near the Marshall Islands (Cushman, Todd, Post, 1954), near Samoa (Cushman, 1924), Lord Howe (Heron-Allen, Earland, 1924) and Gilbert islands (Todd, 1961), in the Yellow and East China seas (Cheng Tsi-Chung, Cheng Sau-Yee, 1960, 1962), near the North American coast (Cushman, Moyer, 1930, in the Gulf of California (Brady, 1953, 1961), on the Chatham Rise (Hornibrook, 1952), near the east coast of Australia (Parr, 1950), and in Bass Strait (Parr, 1945). G. ruber is a typical species from 40°N to 40°S.

108/ In the plankton of the North Pacific (Bradshaw, 1959), this species occurred south of 40°N within the boundaries of equatorial and central waters at temperatures of 15°-32°C; the highest concentrations were found in equatorial waters at temperatures of 27°-32°C. In the southern hemisphere, the species reaches 40°S and comprises up to 20% of the fauna (Parker, 1960) in (water) temperatures of 10°-27.3°C and salinities of 34-36.5°/oo.

In summary, G ruber is a species typical of latitudes 40°N to 40°S and its highest concentrations occur in the tropical zone.

Globorotalia tumida (table 10) was found at 104 stations in quantities of several tens or even hundreds of specimens. Quantities greater than 1,000 specimens occurred at only one station in the Marquesas region. The northern boundary of this species extends to 32°N in the west and to 10°N in the east, while the southern boundary approximately follows 30°S. The species occurred on elevations in the Northwest Basin, near the Bonin Islands, north of the Marianas and Moluccas, near the Tobi Islands, on Eauripik Ridge, in Lamotrek and Ifalik atolls, on the Kapingamarangi Ridge, north and northeast of New Guinea, on elevations in the Melanesian and North Fiji basins, near the Gilbert, Marshall, Tonga, Samoa and Phoenix islands, and on elevations of the Central Basin near the Marshall Islands (47 specimens).

In addition, according to literature data, the species was found on seamounts west of the Hawaiian Islands (Hamilton, 1952), at 7 stations in the region of Philippine Islands and in the Funafuti Atoll region (Chapman, 1900-1902), and in the East China and Yellow seas (Cheng Tsi-Chung, Cheng Sau-Yee, 1960, 1962). There were occurrences in the Gulf of California (Bandy, 1960, 1962) and near the east coast of Australia (Parr, 1950).

In summary, G. tumida is a typical tropical species, which does not form high concentrations in its wide range. Individual encounters with this species were made outside the tropical zone. In Pacific waters, this species occurred only in the tropical region (Bradshaw, 1959; Parker, 1960), with highest concentrations near the equator in waters with a temperature of 29°-31°C.

Sphaeroidinella dehiscens (table 15) occurred on the Pacific Ocean bottom in quantities of up to 576 spcm/g at 92 stations between 10°N and western part of the ocean: on the Markus-Necker Ridge, on elevations in the Northwestern Basin, near the Bonin and Nampo islands, on elevations in the Philippine Basin, between New Guinea and the Caroline islands, near the Solomon Islands, on elevations in the Melanesian Basin, near the Gilbert Islands, in the North Fiji Basin, on elevations in the Central Basin, and near Tuamotu and Samoa. S. dehiscens is most widespread between 20°N and 20°S.

According to literature data, this species was found on seamounts west of Hawaii (Hamilton, 1952), in the Hawaiian Islands (Bagg, 1908), near the Marshall (Cushman, Todd, Post, 1954) and Philippine islands (Cushman, 1921), in Funafuti Atoll (Chapman, 1900-1902), in the East China and Yellow seas (Cheng Tsi-Chung, Cheng Sau-Yee, 1960, 1962). Small specimens were found at two stations near the southern and eastern shores of Australia (Parr, 1950). Rarely, small quantities of the species were found in plankton in the central waters; S. dehiscens, is a typical species in equatorial waters with temperatures of 25°-31°C, but it does not form concentrations and comprises 1-5%, and rarely more than 5%, of the fauna.

S. dehiscens is a species typical of tropical latitudes, where it occurred at all depths. It occurred most frequently and in relatively high proportions in Zone III.

109/ Globigerinata glutinata (table 16) was found between 30°N and 50°S at one station near the North American coast, on elevations in the Northwestern Basin, near the Bonin Islands, in the West Mariana Basin, north of the Moluccas, near New Guinea, south of the Caroline Islands, in the Melanesian, North Fiji and Central Basins, on the Colville-Lau Ridge, on the South and East Pacific rises, and near the Tuamotu and Marquesas islands. The literature reports this species near the Gilbert Islands, in the Gulf of California, and on seamounts west of the Hawaiian Islands (Hamilton, 1952). The species occurred almost everywhere in North Pacific Ocean waters (in subarctic, transitional, central, and tropical waters), but in small numbers. Higher contents were noted in the Gulf of California and in tropical waters near the American coast. Shells from tropical waters are typically much larger than cold water shells. This species occurred at three stations in the southern part of the ocean between 3°N and 43°S and between 80° and 130°W Parker, 1960).

G. glutinata was found in all zones in our data. Based on rare occurrences in low quantities, it is difficult to speak about its distributional features.

Globorotalia crassaformis (see table 10) occurred at stations between 34°N in the west and 50°S. In the Northeast Basin (near the coast of North America), this species was found at one station (one spcm/g) and in the

110/ Table 16. Average content and frequency of occurrence of Globigerinita glutinata (Egger) in sediments at depths in different latitude zones (I-VI).

Depth (m)	Average content, (spcm/g)						Frequency of encounter (p)					
	I*	II	III	IV	V	VI	I	II	III	IV	V	VI
0—200	0	0	0	0	0	0	0	0	0	0	0	0
200—500	0	0	0	—	0	0	0	0	0	—	0	0
500—1000	0	—	22	4,5	—	0	0	—	0,2	0,5	—	0
1000—3000	4,4	7	10	0	24	0	0,07	0,26	0,17	0	0,25	0
3000—3500	0	7	0	5	—	0	0	0,11	0	0,66	—	0
3500—4000	0	0	4	0,2	143	0	0	0	0,27	0,12	1,0	0
4000—4500	0	0	0,6	0	0	0	0	0	0,09	0	0	0
4500—5000	0	0	0	0	—	—	0	0	0	0	—	—
>5000	0,0004	0	0,0002	0	—	—	0,01	0	0,02	0	—	—
Average for the zone (for all depths)	0,08	1,6	2,6	0,87	27	0	0,01	0,05	0,07	0,13	0,22	0

* I-north of 40°N; II-40-20°N; III-20°N-20°S; IV-20-40°S; V-40-60°S; VI-south of 60°S

111/ Table 17. Average content and frequency of occurrence of <u>Candeina</u> <u>nitida</u> d'Orbigny in sediments at depths in different latitude zones (I-VI).

Depth (m)	Average content, (spcm/g)						Frequency of encounter (p)					
	I*	II	III	IV	V	VI	I	II	III	IV	V	VI
0—200	0	0	0	0	0	0	0	0	0	0	0	0
200—500	0	0	8	—	0	0	0	0	0,33	—	0	0
500—1000	0	—	0,3	0	—	0	0	—	0,20	0	—	0
1000—3000	0	1,6	9	5	0	0	0	0,04	0,13	0,40	0	0
3000—3500	0	4	4	3	—	0	0	0,11	0,25	0,33	—	0
3500—4000	0	0	0	0	0	0	0	0	0	0	0	0
4000—4500	0	0	0	0	0	0	0	0	0	0	0	0
4500—5000	0	0	0	—	—	—	0	0	0	0	—	—
>5000	0	0,0008	0,005	—	—	—	0	0,01	0,02	0	—	—
Average for the zone (for all depths)	0	0,54	1,8	1,3	0	0	0	0,02	0,05	0,10	0	0

114

Table 18. Average content and frequency of occurrence of <u>Orbulina</u> <u>universa</u> d'Orbigny in sediments at depths in different latitude zones (I-VI).

Depth (m)	Average content, (spcm/g)						Frequency of encounter (p)					
	I*	II	III	IV	V	IV	I	II	III	IV	V	VI
0—200	0,0005	0	0,1	0	0	0	0,025	0	0,33	0	0	0
200—500	1	0	23	—	45	0	0,06	0	0,33	—	1,0	0
500—1000	0	—	56	6	—	0	0	—	0,8	1,0	—	0
1000—3000	0	44	7	14	0	0	0	0,52	0,48	0,40	0	0
3000—3500	0	11	37	298	—	0,31	0	0,22	0,37	1,0	—	0,25
3500—4000	0	0	3	0,3	71	0	0	0	0,14	0,25	1,0	0
4000—4500	0	0	0,2	0	0,4	0	0	0	0,09	0	0,5	0
4500—5000	0	0	0,2	0	—	—	0	0	0,09	0	—	—
>5000	0,0002	0	0,009	0	—	—	0,01	0	0,02	0	—	—
Average for the zone (for all depths)												

*I-north of 40°N; II-40-20°N; III-20°N-20°S; IV-20-40°S; V-40-60°S; VI-south of 60°S

southern part of the basin near the Marquesas and Tuamotu islands. In addition, this species occurred on elevations in the Northwestern Basin, near the Bonin and Nanpo islands, northwest of the Molucca and Sonsorol islands, in the Caroline Islands region, northeast and southeast of New Guinea, on one elevation in the Central Basin, on slopes of the Norfolk Ridge, in the Tasman Sea, near the northwest coast of New Zealand, on the New Zealand Rise, near Tonga, and on the East Pacific Rise. This species prefers temperate latitudes, especially southern temperate (latitudes), where its average content is 56 spcm/g and its frequency of occurrence is 0.33. G. crassaformis also was found on the Chatham Rise (Hornibrook, 1952). In oceanic waters, the species was found (Parker, 1960) in southern temperate latitudes in ocean water temperatures of 9°-18°C and salinities of 34-35°/oo.

In summary, G. crassaformis's widest range is in tropical and southern subtropical zones. THe species does not occur in high concentration.

Candeina nitida (table 17) occurred at 11 stations between 20°N and 30°S on the eastern part of the Markus-Necker Ridge, on Eauripik Rise, near the Solomon Islands and Tonga, in the North Fiji Basin, and near Tuamotu. In addition, this species was found on two elevations in the Northwest Basin, north of 20°N. Maximum concentrations of the species were 148 spcm/g; it is most typical in latitudes 20°N to 20°S, where its average content is 2 spcm/g and frequency of occurrence is 0.05. According to literature data C. nitida was found in the Hawaii region (Bagg, 1908), between Guam and Yokohama (Flint, 1905), near the Marshall Islands (Cushman, Todd, Post, 1954), on seamounts west of the Hawaiian Islands (Hamilton, 1952), in the East China and Yellow seas (Cheng Tsi-Chung, Cheng Sau-Yee, 1960, 1962), and near the east coast of Australia (Parr, 1950). In Pacific Ocean waters, this species occurred south of 30°N in tropical and warm waters of temperate latitudes and does not form large accumulations anywhere. The content of this species on the stations does not exceed 10%. Maximum concentrations of this species were found near the Hawaiian Islands, while areas of low concentrations occurred in equatorial waters from the Philippines to Panama.

112 This species is rare in the South Pacific Ocean (Parker, 1960), and was found at one station north of 30°S. C. nitida is a typical tropical species.

Orbulina universa (table 18) occurred at stations between 35°N and 35°S: on elevations in the Northwestern and Northeastern basins, near North American coasts, near the Bonin Islands, south of the Carolines and north of the Moluccas, at two stations north and southeast of New Guinea, on the Marcus-Necker Ridge, near the Marshall Islands, around Phoenix and Tokelau islands, in the North Fiji basin, near the Tonga and Kermadex islands, and north of New Zealand. The higherst concentrations occurred in temperate latitudes; in the equatorial region this species occurs very rarely and in low quantities. The literature reports the presence of O. universa in sediments of the Hawaiian (Bagg, 1908) and Philippine islands (Cushman, 1921), near the North American coast (Cushman, Moyer, 1935), in the Gulf of California (Bandy, 1961, 1953), in the East China and Yellow seas (Cheng Tsi-Chung, Cheng Sau-Yee, 1960, 1962) on seamounts west of the Hawaiian Islands (Hamilton, 1953), near the eastern and southern coasts of Australia (Parr, 1950), in Bass Strait (Parr, 1945), and on the Chatham Rise (Hornibrook, 1952).

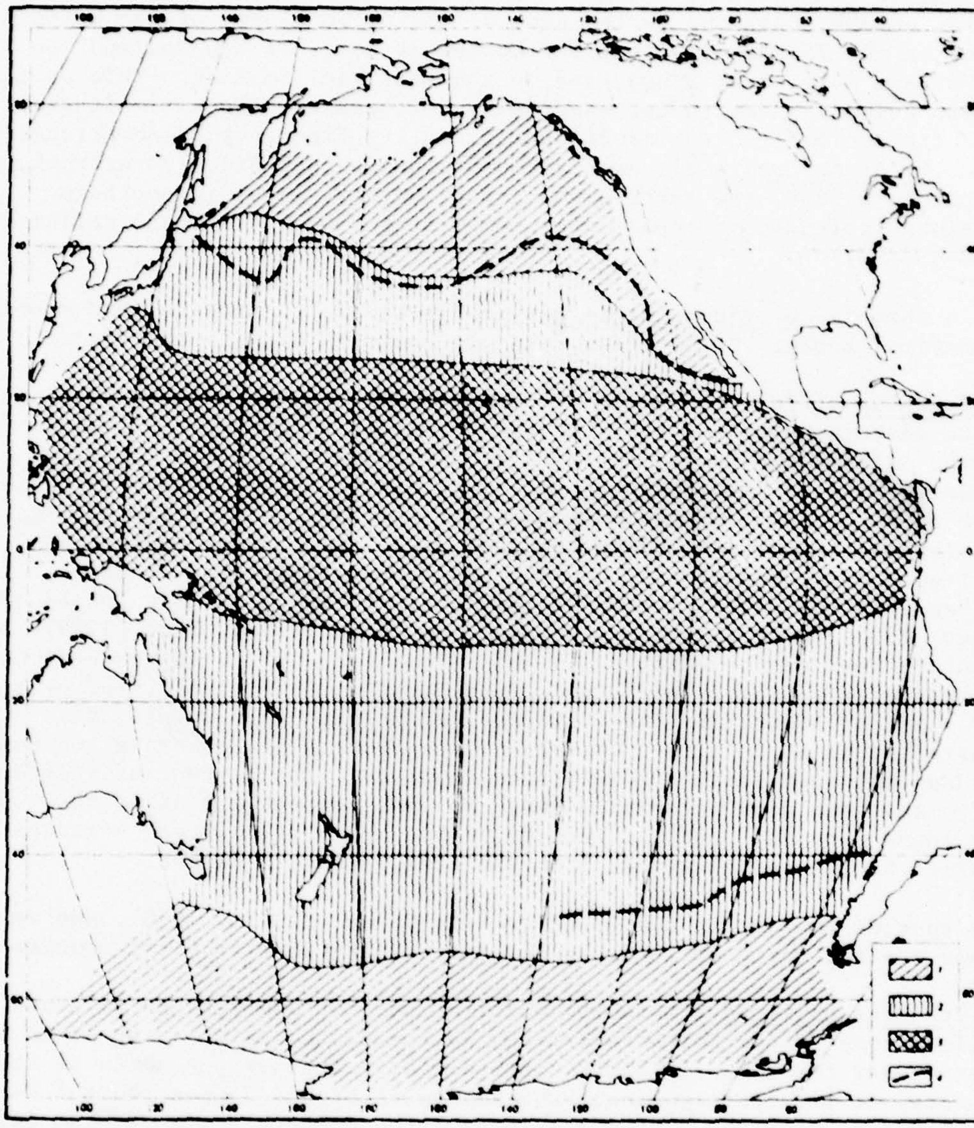


Fig. 43. Percentage correlation of Globigerinidae and Globorotaliidae.

Globigerinidae	Globorotaliidae
1. 100%	1. 0%
2. 50-100%	2. 50-100%
3. <50%	3. >50%

4. Distribution boundary of Globorotaliidae in water.

In Pacific Ocean waters, this species occurred south of 40°N. Maximum concentrations occurred near the North American coast and at several stations near the Japanese coast. In the southern hemisphere, this species reaches 60°S and comprises up to 50% of the fauna, while near the shores of South America, at 20°S, it comprises more than 50% of the fauna. This species is found in water temperatures of 9°-27.6°C and salinities of 33.6-36.5°/oo.

Orbulina universa is a widely distributed species. Its maximum concentrations and high frequency of occurrence were in the tropical zone.

Remaining species--Hastigerina pelagica, Globoquadermia hexagona, Globigerina quinqueloba, Globorotalia scitula, Hastigerinella rhumbleri, Globigerinita humilis, globigerina rubescens, Globigerina helicida, Globigerina callida, Globigerina digitata, Globigerinoides minuta, and Globorotalia pumilio--occurred rarely and in small numbers.

Bradshaw and Parker's works contain distribution charts of all tropical zone species in Pacific Ocean waters (Bradshaw, 1959; Parker, 1960). Comparison of species distribution charts in water and in sediments shows that the range boundaries in the two media coincide completely. The ranges of the species are usually continuous in water, but discontinuous in sediments (due to dissolution of shells on the bottom in deep water basins).

From the discussion above, it can be seen that the range of individual planktonic foraminiferal species on the Pacific Ocean bottom is closely related to their distribution in surface waters and clearly shows geographic zoning in plankton distribution. The quantitative distribution of individual species in sediments depends on underwater relief, which does not distort the geographic zoning, but noticeably changes quantitative characteristics and determines the sporadic character of ranges.

Correlation of the families Globigerinidae and Globorotaliidae in Sediments and Thanatocoenoses

Figure 43 is a diagram of globigerinid (Globigerinidae) and globorotaliid (Globorotaliidae) correlation in sediments. This chart, unlike preceding ones, was compiled without consideration of bottom relief, because its purpose is to show only the latitude range of the families discussed and their relative role in the composition of planktonic foraminiferal fauna.

North of 40°N and south of 50°S, the fauna consist of representatives of the family Globigerinidae. The role of the family Globorotaliidae in planktonic foraminiferal fauna increases in the direction of the equator (up to 50%); and in the latitude band along both sides ofthe equator, this family comprises more than 50% and frequently reaches 100% of the faunal content. Based on such a distribution of the family, it is appropriate to mention the imprecision of the term "globigerina oozes." It is more correct to use the term "foraminiferal oozes" and in reference to different latitude zones one might use the terms "globigerina, globorotalia, and mixed globigerina-globorotalian oozes." Globorotalia oozes are remarkable for the diversity of their species and generic composition, larger shells and their thick walls, as well as their shell sculpture. The distribution of globorotalia on the bottom corresponds to their range in ocean waters.

114/ Table 19. Frequency of occurrence (p) of individual species of planktonic foraminifera in different thanatocoenoses.

Species	Thanatocoenoses*					
	I	II	III	IV	V	VI
Globigerina pachyderma	0,08	0,1	0,06	0,13	0,33	0,47
G. bulloides	0,12	0,28	0,50	0,80	0,90	0,27
Globoquadrina dutertrei	0,03	0,18	0,47	0,43	0,33	0,15
Globorotalia truncatulinoides	0,03	0,16	0,12	0,46	0,55	—
G. inflata	0,03	0,18	0,07	0,70	0,77	—
Globigerinoides ruber	0,02	0,14	0,43	0,63	—	—
Globigerinita glutinata	0,01	0,05	0,07	0,13	0,22	—
Pulleniatina obliquiloculata	0,04	0,12	0,50	0,16	—	—
Globigerianoides conglobatus	0,02	0,10	0,47	0,50	—	—
G. sacculifer	0,01	0,10	0,17	0,33	—	—
Globorotalia hirsuta	0,004	0,04	—	0,1	0,33	—
Globigerinella aequilateralis	0,01	0,1	0,37	0,26	—	—
Globorotalia crassaformis	0,004	0,06	0,11	0,33	0,11	—
G. tumida	0,004	0,11	0,49	0,16	—	—
G. menardii	—	0,17	0,44	0,33	0,11	—
Sphaeroidinella dehiscens	—	0,12	0,44	0,1	—	—
Globorotalia scitula	—	0,02	0,01	—	—	—
Globrquadrina conglomerata	—	0,005	0,25	0,06	—	—
Candeina nitida	—	0,02	0,5	0,1	—	—

*I-Northern boreal; II-Northern subtropical; III-Tropical; IV-Southern subtropical; V-Notal (subantarctic); VI-Antarctic

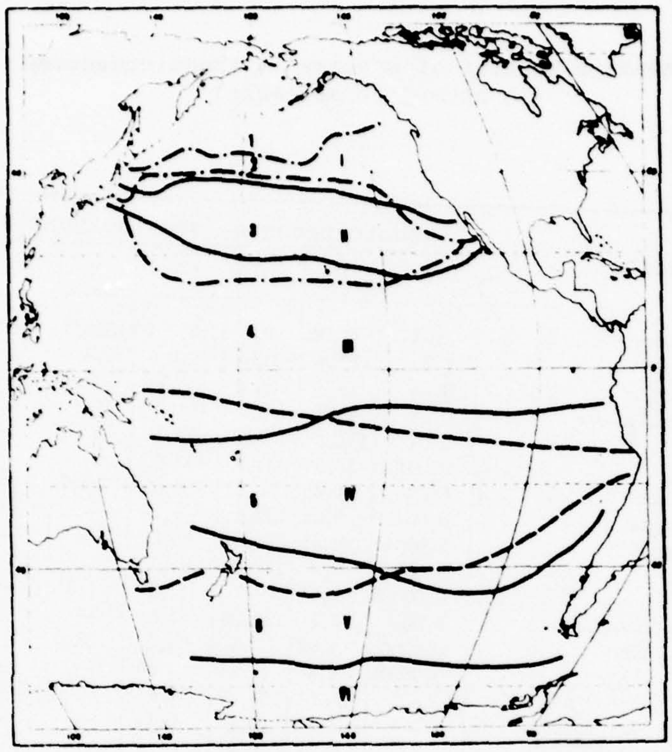


Fig. 44. Thanatocoenoses and biocenoses of planktonic foraminifera

Thanatocoenoses: I-Northern boreal; II-Northern subtropical; III-Tropical; IV-Southern subtropical; V-Subantarctic; and VI-Antarctic.

Biocoenoses (according to Bradshaw, 1960; Parker, 1959): 1-Subarctic; 2-Transitional; 3-Central; 4-Equatorial; 4-South-central; 6-subantarctic.

Solid lines on the chart are the boundaries of thanatocoenoses; dash-dot lines are biocoenoses boundaries according to Bradshaw (1960); dashed lines are biocoenoses boundaries according to Parker (1959).

116/ Table 20. Average content of species in thanatocoenoses (in spcm/g of sediment)

Species	Thanatocoenoses (see footnote table 19)					
	I	II	III	IV	V	VI
Globigerina pachyderma	2,05	11,51	0,1	1343,4	1385,3	248,0
G. bulloides	1,85	113,4	2132	1410,5	5449,5	6,2
Globoquadrina dutertrei	0,03	43,3	110,2	83,7	25,6	6,5
Globorotalia truncatulinoides	0,58	48,8	2,2	191,2	411	—
G. inflata	0,04	173,5	2,4	628,1	3942,4	—
Globigerinoides ruber	0,001	53,6	304,5	173,05	—	—
Globigerinita glutinata	0,08	1,6	2,6	0,87	26,7	—
Pulleniatina obliquiloculata	0,002	5,95	120,1	0,98	—	—
Globigerinoides conglobatus	0,0004	20,53	526,6	63,6	—	—
G. sacculifer	0,001	38,5	142,35	65,7	—	—
Globorotalia hirsuta	0,00008	0,45		2,3	4,8	—
Globigerinella aequilateralis	0,005	6,7	53,36	23,8	—	—
Globorotalia crassaformis	0,00008	4,02	2,4	56,6	53,0	—
G. tumida	0,00008	2,8	47,24	0,86	—	—
G. menardii	—	24,04	64,69	2,1	0,38	—
Sphaeroidinella dehiscens	—	1,6	16,1	0,14	—	—
Globorotalia scitula	—	0,57	0,01	—	—	—
Globoquadrina conglomerata	—	0,49	10,56	0,64	—	—
Candeina nitida	—	0,54	1,8	1,28	—	—

Clear patterns have been found in the distribution of individual species. Range boundaries were established for each species; within these boundaries, zones based on the qunatities of shells of each species (in spcm/g), their percentage content (of the total planktonic foraminiferal fauna), and the extent of the species distribution (frequency of occurrence) were delineated.

On the basis of individual species range and considering the overall quantitative distribution of planktonic foraminifera on the Pacific Ocean bottom, we delineated five thanatocoenoses (fig. 44). Data on frequency of occurrence and average quantity of shells of individual species in all thanatocoenoses have been summarized in tables 19 and 20.

115/ The northern boreal thanatocoenosis was delineated north of 40°N. In this thanatocoenosis, high foraminiferal concentrations were found on submarine ridges at depths less than 3,000 m. Frequency of occurrence of foraminiferal contents greater than 1 spcm/g is very low ($p=0.05$); at most stations, foraminifera are absent or occur in quantities less than 1 spcm/g. These were regions of shelves and great depths.

The main species of this thanatocoenosis are G. pachyderma and G. bulloides. High concentrations of these were found only on ridges and elevations at depths less than 3,000 m, while low contents occurred on greater areas of the bottom. The frequency of occurrence of these species is also lower than in other thanatocoenoses (excluding the Tropical). Consequently, computing average contents of these main species of the thanatocoenosis, one obtains lower values than in neighboring thanatocoenoses. The role of these species in the faunal composition of this thanatocoenosis is extremely important; they comprise up to more than 90% of the fauna and are most numerous and most widely distributed within the thanatocoenosis (tables 9, 19, and 20).

The remaining insignificant part of the fauna is represented by temperate latitude species, which were rearely found in the Northwest Pacific, in areas influenced by the warm Kuroshio Current.

116/ The Northern subtropical thanatocoenosis ranged between 40° and 20°N. Frequency of occurrence of foraminifera contents greater than 1 spcm/g increases to 0.24 in this region.

G. bulloides ($p=0.28$), G. dutertrei ($p=0.18$), G. inflata ($p=0.18$), and G. truncatulinoides ($p=0.16$) are the most widespread species in this thanatocoenosis; their maximum accumulations occur in the thanatocoenosis, and their average contents are respectively 113, 43, 173, and 49 spcm/g of sediment (tables 9-11, 19, 20). These species comprise up to more than 90% of the foraminiferal fauna. G inflata and G. truncatulinoides are the most typical of this thanatocoenosis. In adjacent thanatocoenoses, these species occur much less frequently and in numbers that are several times and, sometimes, several tens of times lower than in the Northern Subtropical thanatocoenosis. In addition, the frequency of occurrency and content of the warmer water species (G. ruber, G. conglobatus, G. sacculifer) increase in this thanatocoenosis.

The Tropical thanatocoenosis was located between 20°N and 20°S. Within its boundaries, large areas of the shelf, continental slope, and ocean bed are occupied by foraminiferal sediments and are characterized by high concentrations of foraminifera. Such a distribution of foraminifera is related to the fact that the "critical" depth descends to 4,500-4,800 m in tropical latitudes, and less than "critical" depths occupy a greater area here than in the other zones. All species found on the ocean bottom were found within this thanatocoenosis. G. dutertrei (p=0.47), G. ruber (p =0.43), Pulleniatina obliquiloculata (p=0.50), G. conglobatus (p=0.47), G. aequilateralis (p=0.37), G. tumida (p=0.49), G. merandii (p=0.44), S. dehiscens (p=0.44), and G. conglomerata (p=0.25) are the most widespread species. The largest
117/ concentrations are formed by the species G. conglobatus (527 spcm/g), G. ruber (304 spcm/g), G. dutertrei (110 spcm/g), P. obliquiloculata (120 spcm/g), and G. sacculifer (142 spcm/g) (see tables 10-15, 19 and 20. Typically tropical widespread species, (G. menardii, G. tumida, G. conglomerata, S. dehiscens, and C. mitida) do not form large concentrations, but their content in this thanatocoenosis is ten times larger than in adjacent ones. These species are absent in the most northern and southern thanatocoenoses having the coldest water. Very high contents of G. bulloides were found in this thanatocoenosis because the small forms of G. dutertrei and other species, which are hard to distinguish from young G. bulloides, were sometimes assigned by the author to G. bulloides.

The Southern subtropical thanatocoenosis was located between 10°-20° and 40°S. The most widespread species in this thanatocoenosis are G. bulloides (p=0.80), G. inflata (p=0.70), G. ruber (p=0.63), G. conglobatus (p=0.50), G. truncatulinoides (p=0.46), G. dutertrei (p=0.43), G. hirsuta (p=0.10). The largest concentrations in this thanatocoenosis are formed by G. bulloides (1410 spcm/g), G. truncatulinoides (191 spcm), and G. inflata (628 spcm), while high concentrations are formed by G. dutertrei (83 spcm/g) and G. ruber (173 spcm/g) (see tables 9-12, 19 and 20). The most typical species are G. inflata and G. truncatulinoides.

The Subantarctic thanatocoenosis was located between 40° and 60°S; foraminifers occurred at 7 of 10 stations in quantities greater than 1 spcm/g (p=0.77). Ten species were found in this thanatocoenosis. The widest ranging species are G. bulloides (p=0.90), G. inflata (p=0.77), G. truncatulinoides (p=0.55), and G. pachyderma (p=0.33). These species form the largest concentrations here (see tables 9, 10, 19 and 20) and are typical species of this thanatocoenosis.

The Antarctic thanatocoenosis was located south of 60°S. At 24 out of 55 stations, foraminifers were found in quantities greater than 1 spcm/g (p=0.43). Practically, only two species occurred in this thanatocoenosis: G. pachyderma (p=0.47); 248 spcm/g) and G. bulloides (p=0.27; 6 spcm/g) (see table 9, 19, and 20).

Comparison of thanato- and biocoenotic boundaries showed that they coincide. The species composition, correlation of species, and their role in the faunal composition in biocoenoses and thanatocoenoses (at greater than "critical" depths) are identical. High concentrations on the bottom

are formed by species that also produce high concentrations in water. Species that are of rare occurrence and few in the water, never form high concentrations on the bottom. On the bottom of depressions below the "critical" depth, where the shells are subject to dissolution, the correlation of species is distorted: species most resistant to dissolution and not those with the highest population density begin to predominate. This phenomenon is also the cause of frequent gaps in species ranges on the bottom. Prevalence of planktonic foraminifera on the bottom is considerably smaller than in water (for the corresponding bio- and thanatocoenoses).

The shells of planktonic foraminifera dissolve on the bottom of the ocean. This is confirmed by study of their distribution in the water column. For example, the distribution of planktonic foraminifera was studied in the 0-4,000 m water layer in the Indian Ocean (Belyayev, 1964). No traces of shell dissolution were detected in suspension there. However, a large quantity of shell fragments were found on the bottom at the same stations. The rather large shells of planktonic foraminifera take so long to descend to the bottom that they have almost no time to dissolve. Only their long stay on the bottom at greater than "critical" depths leads to their dissolution. At the same time, it has been found that different species dissolve at different rates. Shells of the genus *Hastogerina* dissolve more easily than other shells, while the species *P. obliquiloculata* is the most durable.

Conclusions

The following conclusions can be made on the basis of general study of the quantitative distribution of planktonic foraminifera and individual species ranges.

1. The distribution of planktonic foraminifera on the bottom is closely related to their productivity in the surface water layer (0-200 m), to the relief and depth of the ocean, and (on the shelf and continental slope) also to dilution by terrigenous material.

On continental shelves, planktonic foraminifera occur in sediments in insignificant numbers; this phenomenon is related to the lower productivity of foraminifera over the shelves and to dilution by terrigenous material.

In the waters above the continental slope, planktonic foraminifera occur in large numbers. However, in continental slope sediments in the northern and southern parts of the ocean, foraminifera also form low concentrations due to a large terrigenous admixture. In the tropical part of the ocean, large numbers of planktonic foraminifera occur all over the continental slope and often form pure globigerina deposits.

In the open parts of the ocean north of 20°N and south of 40°S, planktonic foraminifera form high concentrations only on submarine ridges and elevations at less than 3,000-3,500 m depths. Below these depths, planktonic foraminifera are absent due to calcium carbonate solution on the bottom.

Between 20°N and 20°S, planktonic foraminifera occur on the ocean bottom at depths less than 4,500-4,800 m; consequently, in this region, globigerina sediments are developed not only on ridges, but frequently also on basin slopes.

2. Twenty-five species of planktonic foraminifera have been identified and their distribution on the ocean bottom has been studied (in spcm/g of sediment and in percent of the total planktonic foraminiferal fauna) in sediments of the Pacific Ocean.

3. The distribution of the total quantities of planktonic foraminifera as well as of individual species is closely related to latitudinal (climatic) and vertical (hypsometric) zoning. Climatic zoning is revealed in the frequency of foraminiferal occurrence overall, in high concentrations, in average contents (at the same depths), and in the increase in number of species as one moves from low to high latitudes.

At the same time, the correlation between famil ies (Globigerinidae and Globorotaliidae), as well as between individual genera and species changes sharply. In addition, shell sizes also increase and the structure of the shell walls and their markings is altered.

Vertical zoning is shown in the occurrence of planktonic foraminifera in sediments only to certain depths in all latitudes. The location of the "critical" depth of foraminiferal distribution changes in a regular sequence from 3,000-3,500 m in the north to 4,500-4,800 m in tropical latitudes.

4. The distribution of individual species, considering the pattern of the overall quantitative distribution was the basis for delineating planktonic foraminiferal thanatocoenoses on the Pacific Ocean bottom. Six thanatocoenoses were defined: boreal, northern subtropical, tropical, southern subtropical, subantarctic (notal), and Antarctic thanatocoenoses. A definite set of species and definite quantitative and percentage correlations of species are typical of each thanatocoenosis.

5. Comparison of thanato- and biocoenotic distribution charts shows that the boundaries of the main thanatocoenoses in sediments coincide with the
119/ boundaries of the biocoenoses in the water. At depths less than 3,000-3,500 m in high latitudes and less than 4,500-4,800 m in low latitudes, species composition, frequency of occurrence, and correlations within thanatocoenoses coincide almost completely with species composition and species correlation in biocoenoses. Dissolution of planktonic foraminifera occurs on the bottom of deep-water basins, and the rate of dissolution of different species varies. Consequently, identification of species composition and species correlation in bio- and thanatocoenoses is distorted. The species that dissolves most slowly, and not the species that are most abundant in the water begin to play the most important role in the thanatocoenoses. It seems that in all cases, one can define a particular biocoenosis and its environment (latitude zone, water temperature), and burial conditions (depth) based on the thanatocoenotic composition and correlation of individual species (true or distorted during dissolution).

6. The conclusions reached on the distribution of planktonic foraminifera in the Pacific Ocean can be used in further study of bottom sediment stratigraphy and in reconstruction of paleogeographic conditions of the geologic past.

Chapter IV

Distribution and Ecology of Recent Benthonic Foraminifera in the Pacific Ocean

Introduction

The study of contemporary benthic foraminifera of the Pacific Ocean was made for the further purpose of their use in stratigraphic, facies, and paleogeographic problems.

In the study of contemporary foraminifera of the Pacific Ocean we used samples collected by the R. V. VITYAZ and OB' (at approximately 600 stations) and published data from foreign oceanographic expeditions (700 stations), which dealt in some way with the composition and distribution of foraminifera.

Many works dealing with contemporary foraminiferal fauna of the Pacific Ocean were published in the 19th and early 20th centuries. The classification of foraminifera since that time has undergone considerable changes, expecially as to definition of genera. Theories about the range of species have also changed drastically. Consequently, we had to completely revise previously described forms of the Pacific Ocean taking into account the new classification of foraminifera (Fursenko, 1959; Loeblich, Tappan, 1964) and data on their ecology. It cannot be said that it was possible in this work to solve all the puzzling problems that usually arise during such reviews of fauna. Frequently, there were insufficient data on the exact location of certain species holotypes and their complete descriptions. The absence, in some studies, of graphic representations and descriptions of the species encountered made it impossible to make full use of these materials in reviewing the classification of species of foraminifera and their distribution. This statement especially applies to works of the last and early present centuries (Bagg, 1908; Chapman, 1922; Cushman, 1910-1916; Goes, 1896; Heron-Allen, Earland, 1924; Flint, 1905).

All currently available data on the distribution of benthic foraminifera in the Pacific Ocean were used in the present work. The foraminiferal fauna of the marginal seas of the Pacific Ocean are not discussed in this work, because of their isolation and the special peculiarities of the foraminiferal species composition and distribution that have evolved in each sea. Descriptions of the species encountered and their graphic portrayal will be presented in a special study.

The present chapter contains data on the distribution patterns and ecology of the main taxonomical groups of benthic foraminifera and on the most favorable conditions for their existence. Percentage contents based on the number of species in the orders and on their population size, also are presented; the principal types of fauna and taxocoenoses of Pacific Ocean foraminifera were determined. All data on population size of species, genera, and orders were processed statistically. When there were enough stations, the average geometric content of specimens was calculated, while the arithmetic mean was calculated in some other cases.

121 At the present time even greater attention is paid to the foraminiferal distribution pattern. Environment is the determining factor in foraminiferal distribution. Investigations in this direction (Rauger-Chernousova, Reitlinger, 1962) expose the selection of different species of foraminifera relative to certain conditions of the environment. At the present time there is no agreement as to the principal environmental parameters that control the distribution of foraminifera. Many authors think that the main factor is water temperature (Berry, 1931; Natland, 1933; Phleger, 1951; Bandy, 1953; 1956; Parker, 1960) or salinity (Post, 1951; Said, 1951; Parker, 1955). Some authors give depth as one of the important factors in the distribution of foraminifera (Norton, 1930; Hoglund, 1947), while others-water density (Hendrix, 1958). Most researchers conclude that the sum of all environmental factors determines the spatial distribution of foraminifera (Pratie, 1930; Shchedrina, 1956, 1957; Myers, 1957; Zalesny, 1959; Saidova, 1958, 1959, 1962).

History of Research

The quantitative and qualitative distribution of benthic foraminifera in contemporary seas and oceans has been almost unstudied to the present time. In this respect, the Indian, Atlantic, and Arctic oceans appear as blank areas. In the southern ocean data exist only in the Indian sector (Saidova, 1961). In the Atlantic sector, the quantitative distribution of foraminifera has been studied in the Gulf of Mexico by estimating the fauna per given volume of sediment (Phleger, 1951, 1955, 1956, 1960; Lankford, 1959; Bandy, 1956; Lynts, 1962) as well as the Portsmouth region of the English coast (Phleger, 1952).

In the equatorial Atlantic Ocean, data on the distribution of foraminifera exist only for the Orinoco River delta region. In this region, 200 specimens of all types of foraminifera were counted in each sample, and the content of each species was calculated relative to this quantity (Drooger, Kaasschiter, 1958).

In the Pacific Ocean, the quantitative distribution of benthic foraminifera was previously studied in the Okhotsk and Bering seas

(Saidova, 1955, 1959) and in one region in the northern part of the East China Sea (Bezrukov, Murdmaa, Filatova, Saidova, 1958). All studies of Pacific foraminifera deal mainly with their classification. The description of species in these studies is accompanied by a list of stations complete with coordinates, depths, and occasionally water temperature. These works contain no exact quantitative distribution per sediment weight or bottom area. Sometimes there are determinations of the "much","medium", "little" type. The work of large expeditions, which deal with foraminifera of coastal as well as the open ocean, can be included with these works generally of taxonomic type. With these works belong the data collected by the CHALLENGER (Brady, 1844; Cushman, 1925), CARNEGIE (Cushman, 1924; Revelle, 1944), ALBATROSS (Cushman, 1921, 1932, 1934, 1932-1942), SIBOGA (Hofker, 1927), VALERO III (Cushman, McCulloch, 1939, 1940, 1942, 1948; Lalicker, McCulloch, 1940), and NERO and TUSCARORA (Cushman, 1910-1916).

In the Pacific Ocean, based on various local expeditions,
foraminifera were found in Japanese coastal regions (Asano, 1937,
1951-1960; Morishima, 1955; Shchedrina, 1958), along the California
coast (Bandy, 1953; Brenner, 1962; Crouch, 1929; Cushman, 1927;
Cushman, Moyer, 1930; Cushman, Valentine, 1939; Walton, 1955), near
British Columbia (Cushman, 1925c), North America (Cushman, 1927;
Natland, 1933), Central America (Bandy, 1956), South America (Cushman,
122 Kellett, 1929); Hawaiian Islands (Bagg, 1908), Juan Fernandez Islands
(Cushman, Wickendur, 1929), Funafuti Atoll (Chapman, 1900-1902, 1902),
the Marshall Islands (Cushman, Todd, Post, 1954; Todd, Post, 1954),
in the lagoons of the Kapingamarangi Islands (McKee, Chronic, Lopold,
1959), near the coasts of New Zealand (Chapman, 1905), and Australia
(Chapman, 1905) and Australia (Chapman, Parr, 1935; Chapman, 1941;
Heron-Allen, Earland, 1922), in the Ross Sea (Chapman, 1916; Warthin,
1943), and near the Malayan Achipelago (Millett, 1898-1904).

All these sources were used in the present chapter to classify foraminifera and to determine the presence or absence of one and other species and their relative quantity and ecology.

The latest foreign reports on Pacific foraminifera contain, in addition to classification data, data on the quantitative distribution of foraminifera. These reports deal mainly with narrow coastal regions: Santa Monica Bay near Los Angeles (Zalesky, 1959), Gulf of California (Uchio, 1960; Bandy, 1961) the coast near San Diego (Butcher, 1951), the Pacific sectors of the Antarctic coast (McKnight, 1962), and the Ross, Amundsen, and Bellingshausen seas (Pflum, 1963). The authors give the quantity of foraminifera per unit weight of sediment. Other studies contain data only on the percentage content of foraminifera. These works include studies of the Pacific coast of Japan (Uchio, 1959a & c, 1962a, c; Sawai, 1958), the Yellow Sea (Polski, 1959), the China coast from Shanghai to Hainan Island and

Gulf of Tonkin (Waller, 1960). Soviet investigators covered the open regions of the Pacific (Saidova, 1958, 1959, 1961b, 1962, 1963, 1964), whose foraminifera were counted per unit weight of sediment.

None of the foreign works contain summaries of the distributions and ecology of large taxonomic groups of benthic foraminifera. Some works mention only vertical zones, classified in terms of foraminifera in individual shallow water regions of the ocean or marginal seas (Shchedrina, 1956; Saidova, 1961a; Natland, 1933: Butcher, 1951, Crouch, 1952; Bandy, 1953; Walton, 1955).

Analysis Methods

In order to obtain data suitable for comparison of the quantitative distribution of foraminifera, as well as their taxonomic compostion and ecology, one must have accurate estimates of fauna by species as well as by main taxonomic groups. Consequently, practical execution of the work included counting foraminifera in dry sediment samples of given weight. 50-to 300-g weighed samples of dry sediment were taken from the uppermost layer of bottom dredge samples. The sediment was placed in a small No. 76 miller's gauze pouch that can pass only particles smaller than 0.05 mm. Washing continued until the water became clear. Foraminifera smaller than 0.05 mm seldom are found, and then only as individual specimens in Pacific Ocean sediments. In further processing, the remaining sediment was washed from the pouch into Petri dishes and dried in the desiccator. The clayey sediment from the cup also was dried. When the sediment becomes dry, the foraminifera can be separated from it.

In processing samples from northern regions of the Pacific Ocean, where planktonic foraminifera rarely are found in the sediments because of the great depth, the bottom species were separated from the sediment using a heavy liquid (carbon tetrachloride) with a specific weight of 1.59 (Cushman, 1948; Saidova, 1961a). To separate out the foraminifera, the sediment in Petri dishes was covered with a quantity of carbon tetrachloride sufficient to form a free layer of this liquid above the sediment.

123 The entire content was then stirred with a glass rod. The planktonic and benthic foraminifera floated. The liquid together with the foraminifera was poured over a filter made of the gauze previously mentioned. After evaporating the carbon tetrachloride, the foraminifera were poured into Frank chambers. The sediment samples from more southern regions of the Pacific Ocean were not treated with carbon tetrachloride, because the entire mass of planktonic foraminifera floats up together with the benthic foraminifera. In these cases the benthic shells were separated out by means of a small artist's brush under MBS-1 binoculars. In studying foraminifera from cores of bottom deposits, we used the samples from

mechanical analysis of the sediments. The foraminifera were separated from the fraction less than 0.01 mm. In further processing, the foraminifera were poured out on a glass slide divided into squares, from which the number of shells of different species and the total quantity of foraminifera were calculated.

After all the values obtained were matched with their stations, distribution charts for individual species or taxonomic groups of foraminifera were compiled. Areas of equal population densities (individual forms and totals) were delineated based on water depths, bottom relief, grain and material sediment composition, temperature, salinity, and dissolved oxygen content of the bottom water mass. All charts and graphs of quantitative distribution of foraminifera were based on their content per 50 g of dry natural sediment.

Living and dead specimens of benthic foraminifera were counted together, which made it possible to obtain mean long term data on the contemporary distribution of foraminifera in the Pacific Ocean and make further use of these data to interpret foraminifera distribution in Quaternary and older deposits.

The investigation analysis of the data revealed that bottom foraminifera are distributed everywhere in the Pacific Ocean. No regions were devoid of them. The study of foraminifera distribution was based on two groups of foraminifera with secreted and with agglutinated shells.

AGGLUTINATING FORAMINIFERA

General Quantitative Distribution

The agglutinating foraminifera occur in the entire water column in the Pacific Ocean down to maximum ocean depths (fig. 45). Their shells are composed of various materials and are built principally of varied particles - grains of quartz, calcium carbonate, feldspar, mica flakes, etc, and, more rarely, of sponge spicules and shells of other foraminifera. The choice of agglutinated material depends mainly on its specific weight. Most of the main species choose mineral grains with high specific weight. The agglutinated particles are cemented together by secreted calcareous or ferrous cement with different admixtures (Slama, 1954; Faure-Fremiet, 1911). The relative quantity of cement and agglutinated material in shells is very variable. In shallow warm-water forms that live in the tropics at depths of less than 500 m, calcareous cement predominates over the agglutinated particles. The shells of cold-water, shallow-water, and deep-water forms contain more agglutinated than secreted material.

In the coastal regions of the western part of the Pacific Ocean boreal region, agglutinating foraminifera occur much more rarely than

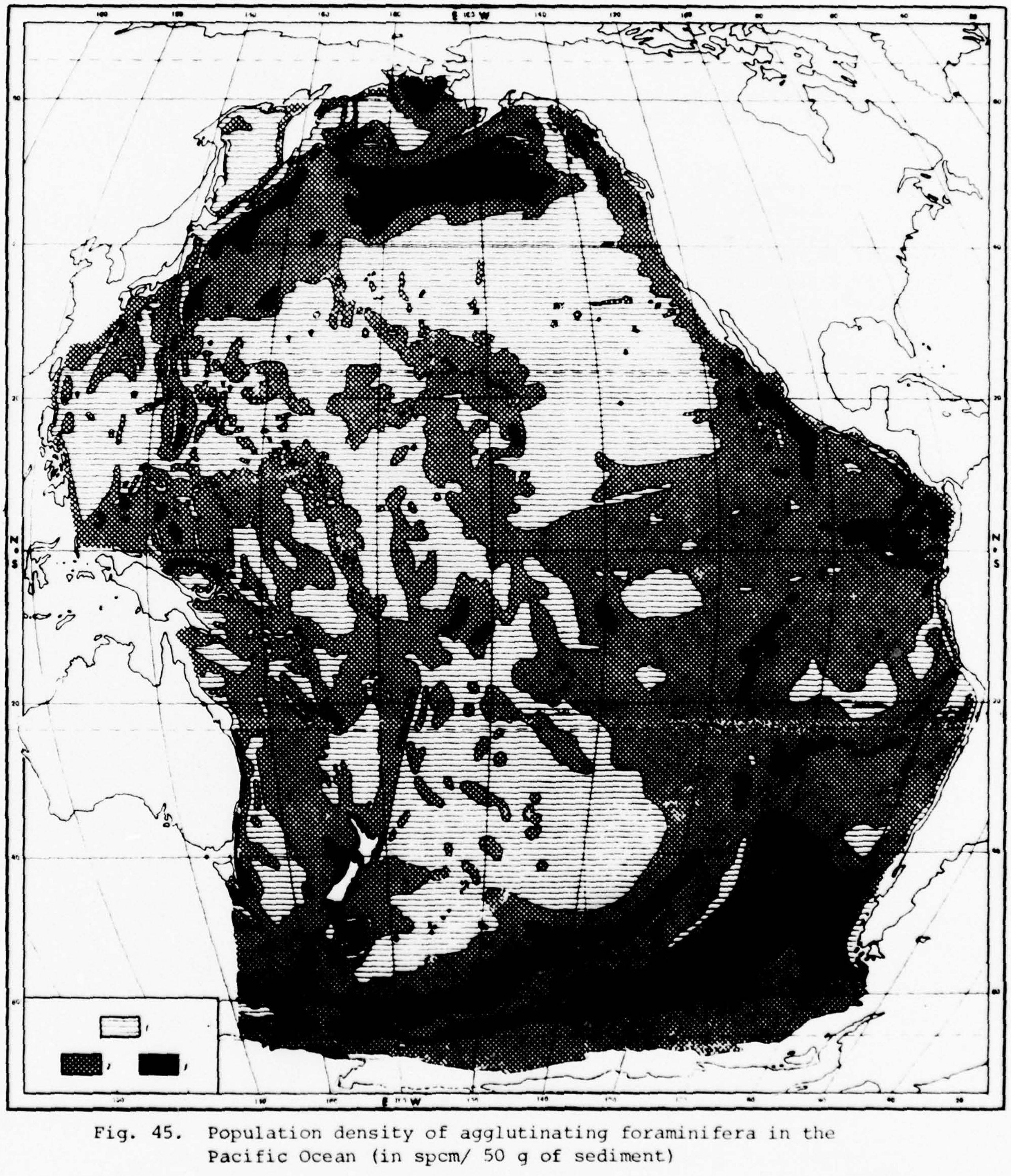


Fig. 45. Population density of agglutinating foraminifera in the Pacific Ocean (in spcm/ 50 g of sediment)

1. less than 25; 2. 25 to 200; 3. more than 200.

124 secreting ones, and their quantity does not exceed 425 spcm per 50 g of sediment. On the coastal slopes of the Aleutian, Kurile-Kamchatka and Japan trenches, they occurred in small quantities. Below 8,000 m, on coastal and oceanic slopes of the trenches, the population density of these foraminifera decreases to isolated specimens.

In the open parts of the ocean, agglutinating foraminifera were found everywhere and their population density is considerably larger than in coastal regions. The greatest numbers occurred in the region of Zenkevich (1,200 spcm) and Obruchev (250 spcm) Rises and on the slopes of the Emperor Seamounts (650 spcm). Deeper in the basins, the population density of agglutinating foraminifera decreases to 50 spcm, while below 6,500 m, it does not exceed 30-40 spcm.

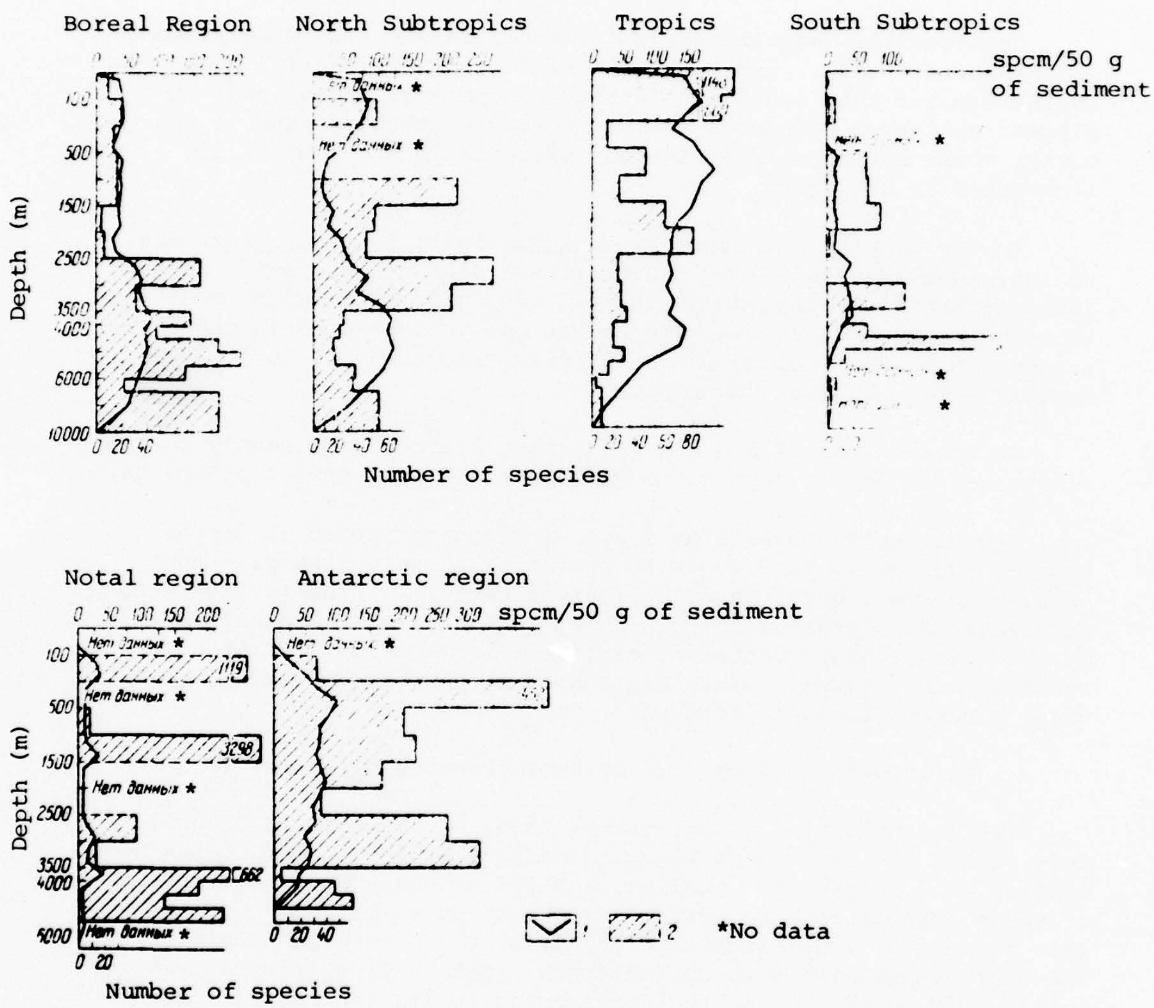
In the eastern part of the boreal region, agglutinating foraminifera occurred in greatest quantities at depths greater than 2,500 m. In coastal regions, at depths of 2,500 to 4,500 m, their population density is not more than 150 spcm, and in the northern part of the Northeast Basin, there are more than 400 spcm at 4,500 to 6,000 depths. In the more southern parts of the basin, only individual specimens occur. In the boreal region, their greater population density typically occurs at depths greater than 2,500 m (fig. 46).

In the tropical region of the Pacific Ocean agglutinating foraminifera increase in density in regions near the principal ridges and rises. The largest numbers of foraminifera (200 spcm) were on the ocean side of the Japan, Isu-Bonin, Volcano, and Marianas trenches and in the Tasman Sea (200-500 spcm), and in the East and West Caroline Basins (600-1,200 spcm). The foraminifera occurred in fairly large quantities near Nanno, Borodino, and Koror islands, near the Hawaiian Islands, and near the coasts of Australia and New Zealand. In the western tropical region, agglutinating foraminifera are especially numerous in the Cocos Ridge and Carnegie Rise regions, on elevations on the ocean side of the American Trench, around the northern end of the East Pacific Rise, and along the Sala Y Gomex and Nasca ridges. In the tropics, agglutinating foraminifera typically occur in greatest quantities at 1,000 to 3,500 m depths in the northern subtropics, at 0 to 300 m depths in the tropics, and at 3,000 to 5,000 m depths in the southern subtropics.

In the notal region of the Pacific Ocean, the greatest density of agglutinating foraminifera is in coastal regions and on slopes of the Bellingshausen Basin (1,000-1,700 spcm). In the South Pacific Basin, their quantities are lower (approximately 500-900 spcm).[1]

In the Antarctic these foraminifera occur in considerable numbers on the bottom of the Bellingshausen Basin and on the continental slope

[1]The quantity of specimens is always given per 50 g of dry sediment.



125 Figure 46. Variation of agglutinating foraminiferal content with depth in different zoogeographic regions of the Pacific Ocean.

1. number of species; 2. geometric mean content of specimens per 50 g of sediment.

of Antarctica. Their greatest densities occur at depths of 300 to 3,500 m.

Consequently, agglutinating foraminifera are more widespread in the boreal, notal, and Antarctic regions of the Pacific Ocean at depths greater than 2,500 m. Terrigenous non-calcareous and, in places, siliceous sediments are widespread at these depths in the north, while organogenic siliceous sediments (diatom oozes) are widespread in the south.

In the tropics and subtropics, agglutinating foraminifera are not as widespread as in more northern and southern regions. These foraminifera form large deposits at 1,000 to 3,500 m depths near the bases of seamounts, ridges, and elevations in the northern subtropics, at less than 500 m depths in the tropics, and at 3,000 to 5,000 m depths in the southern subtropics.

125 At greater than 4,500 m depths, they are confined mainly to red clays and, at lesser depths, to carbonate and terrigenous sediments.

Agglutinating foraminifera are widely distributed at depths greater than 2,500 to 3,000 m in regions with very high plankton biomass (boreal, notal, and Antarctic regions). It seems that enough nutrients reach great depths in these regions. In the other regions of the ocean, large quantities of foraminifera occur at depths greater than 2,500 m only in regions of deep-water upwelling, i.e. where plankton biomass increases.

Distribution of Species of Agglutinating Foraminifera

The agglutinating foraminiferal fauna of the Pacific Ocean is very rich. At the present time it consists of about 500 species belonging to 4 orders, 13 families, and 104 genera. The relationship of these foraminifera to (water) depths is quite varied. Depths less than 2,000 m are inhabited mostly by the more stenobathic species. The depth range within which individual species live is usually very small - 250 to 500 m. On the continental shelf, the habitat depth range of most species is within 100 to 200 m limits. Species with habitat ranges of 1,000 to 3,000 m live mainly in depths greater than 2,000 m. But there are species (about 25%), whose habitat depth range is as narrow as that of shallow-water species. Consequently, if the habitat depth ranges of all agglutinating species are compared, one obtains a graduated picture of their vertical distribution. Each step begins with a certain number of the more stenobathic species and ends with the less stenobathic (fig. 47).

In compiling the graphs for each species, the habitat depth ranges were plotted along the vertical axis. All species were grouped at the

upper depth limit of their habitat range. These groups were divided into a series of fairly obvious steps. In each step, the species were placed in a row based on the decrease in their habitat depth range, i.e. in the order of increase of habitat depth range. Consequently, within the limits of each step, the endemic species are on the left, while relatively eurybathic species are on the right. At the top (along the horizontal axis) is a scale showing number of species (each division contains 10 species), on the left is the depth scale.

In the Pacific Ocean are 22 such steps. The steps are 50 to 100 m high over the shallows and increase gradually with depth to 500 to 1,000 m. In other words, vertical graduations, each represented by independent groups of species can be distinguished in the Pacific Ocean. Each group contains several endemic species.

In the Pacific Ocean as a whole, very few (80 to 123) agglutinating foraminiferal species are found at all depths. An exception is the ultra-abyssal zone (below 6,000 m), where only 50 species (11.4%) occurred. In spite of such homogeneity in the vertical quantitative distribution of species (fig. 48), one can distinguish horizons in which greater numbers of species occur. These depths are between 100 to 300 m, 400 to 1,000 m, 1,500 to 2,000 m, and 2,750 to 3,500 m. The fewest species were at depths of 1,000 to 1,500 m, 2,000 to 2,750 m, and below 6,000 m.

The latitudinal distribution of agglutinating species is generally as diverse as the vertical. The main difference consists of the following: the numbers of agglutinating foraminiferal species that usually live at different depths is very similar, but vary widely with latitude. In the boreal region of the Pacific Ocean are 94 species, in northern subtropics - 128, in the tropics - 345, in the southern subtropics - 89, in the notal region - 8, and in the Antarctic - 108 species. Consequently, the number of species increases toward the equator. The largest number of species is typical of the tropics, while the lowest (is typical) of boreal and notal regions (fig. 49).

In studying the quantitative distribution of species and their population density by depth and latitude, one can see that these quantities change with depth in different latitude regions of the Pacific Ocean (fig. 46). In the boreal region the greatest number 25 to 30) of agglutinating foraminiferal species and shells occurred at depths greater than 2,500 m, where these foraminifera are represented by twice as many species and twice as many shells. Water temperature at these depths is 1.43 to 1.74°C. In the northern subtropics, based on the vertical distribution of species, a large
128 number (up to 75) occurred at depths less than 400 m and in water temperatures of 10 to 20°C. Only half as many species occurred at 400 to 2,500 m depths, while the greatest number of species was found

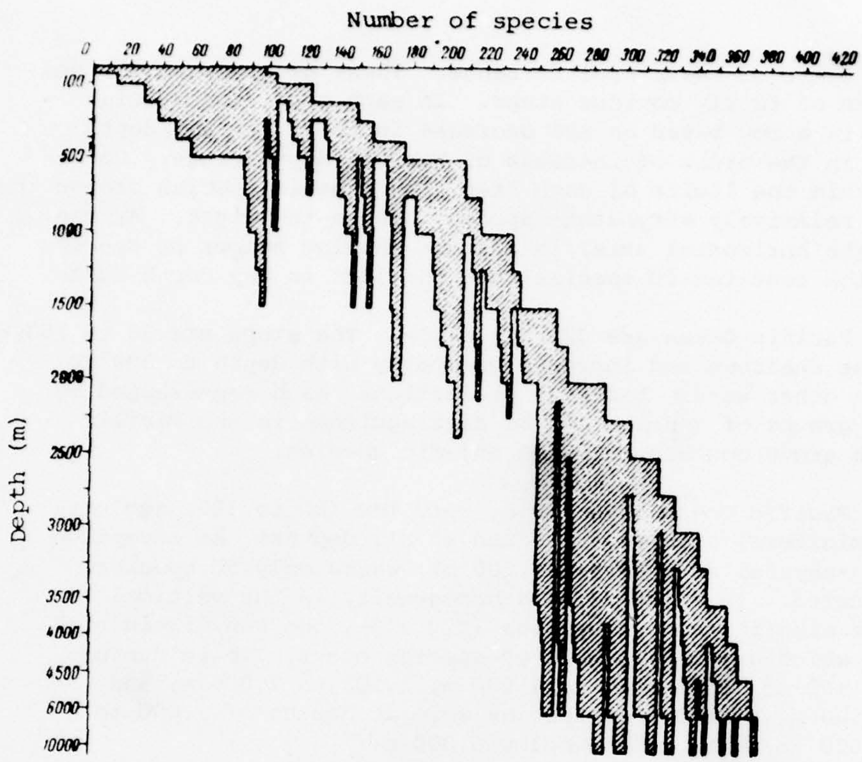


Fig. 47. Quantitative distribution by depth of agglutinating foraminiferal species in the Pacific Ocean.

at depths greater than 2,500 m and in water temperatures of 1.47 to
128 2°C. The following depths can be distinguished based on the largest number of shells: 2,500 to 3,500 m and less than 1,500 m. In the tropics the number of species at different depths is very similar and greater than in other regions. Relatively large numbers of the species were found at 0 to 300 m, 400 to 2,000 m, and 4,000 to 5,000 m depths. The largest number of shells of these species occurs at depths of less than 500 m and of 1,500 to 2,500 m. In the southern subtropics, the number of species is quite insignificant at all depths. A small number of species live at depths less than 2,500 m and greater than 3,500 m and the number of species increases at intermediate depths. The water temperature fluctuates within limits of 1.5° to 2°C here. These species, although few, consist of a large quantity of specimens, especially at 1,000 to 3,500 m depths. In the notal region, the number of species is insignificant as in the southern subtropics. In some places they are represented by large numbers of specimens, especially at depths of 100 to 300 m, 1,000 to 1,500 m, and greater than 3,500 m. In the Antarctic region the number of agglutinating

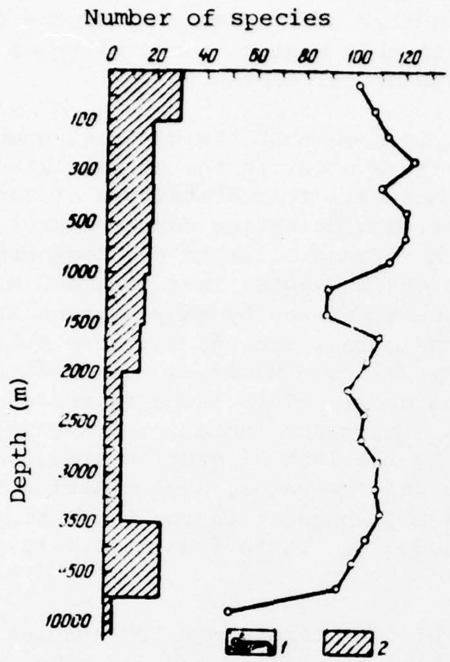


Fig. 48. Quantity of agglutinating foraminiferal species at various depths in the Pacific Ocean.
1. total number of species; 2. number of endemic species in various vertical zones.

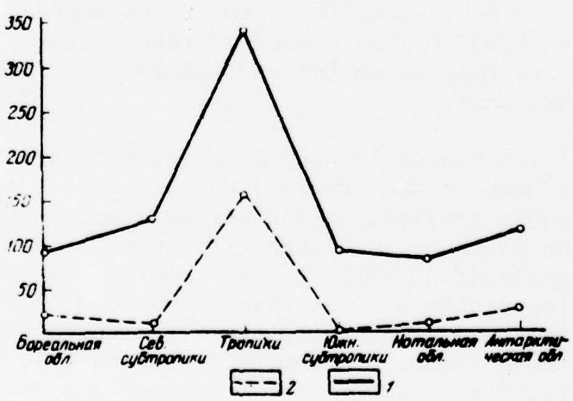


Fig. 49. Variations of the total number of species and endemic agglutinating foraminifera related to latitude in the Pacific Ocean.
1. overall quantity of species; 2. number of endemic species.

foraminifera is twice as large as in the notal region. The species are represented by the greatest number of specimens at depths of 300 to 500 m and 3,000 to 3,500 m. In this region, the density of agglutinating foraminifera is high at all depths.

From the above material, it is seen that the greatest number of species of agglutinating foraminifera occur in the tropics at depths less than 1,500 m (fig. 46). Almost all representatives of contemporary warmth-loving, shallow-water, agglutinating foraminiferal fauna were found there. Elements of this fauna occur in the northern and southern subtropic and notal regions at depths less than 400 m. Agglutinating foraminifera are characterized by many species at depths greater than 2,500 m in the boreal region, northern subtropics, and tropics. In these depths typical cold-water and deep-water agglutinating foraminiferal fauna occur. This fauna is represented by fewer species in the southern subtropics, notal, and Antarctic regions; which can be explained by the lack of stations studied in the latter regions. Cold-water, shallow-water, agglutinating foraminiferal fauna are most diverse and abundant in the Antarctic regions at depths of less than 1,000 m. These fauna are very poor
129 in the boreal region.

As mentioned above, at the present time about 500 species of agglutinating foraminifera have been identified and described in the Pacific Ocean. The presence of a large number of vertically endemic species at depths less than 100 m is typical of the entire Pacific Ocean (fig. 48). Deeper the number of endemic species decreases gradually down to 2,000 m. The fewest of these are in the bathyal zone at 2,000 to 3,500 m depths. In the abyssal zone, at depths of 3,500 to 6,000 m, endemic species are almost as numerous as in less-than-100-m depths, while in the ultra-abyssal zone, at depths greater than 6,000 m, the number decreases again; it is possible that this is related to the current lack of information on the ultra-abyssal zone.

The number of latitudinally endemic species of agglutinating foraminifera is largest in the tropics, where they are represented by 152 species, and is smallest in the northern and southern subtropics. North and south of the latter (regions), endemic species increase only slightly (fig. 49). In the tropics, 78% of endemic species characterize depths of less than 2,000 to 3,000 m, while in the subtropics their numbers decrease sharply. Up to 13 species were observed in the northern subtropics, of which only 30% live at depths less than 2,000 to 3,000 m, the remainder are deeper. In the southern subtropics, the number of endemic species drops to one, and even this occurs at depths greater than 2,000 to 3,000 m. In the boreal region, the number of endemic species increases to 22, and 73% of these live at depths of less than 2,000 to 3,000 m, while in the Antarctic regions the number increases to 18, 80% of which also are at depths less than 2,000 to 3,000 m.

The remaining agglutinating species of foraminifera move from one latitude region to another. These species can be called latitudinally transitional. The greatest number of transitional species move between northern subtropics and tropics, and the smaller number move between the tropics and southern subtropics. Consequently, the
130 agglutinating foraminiferal fauna of the Pacific Ocean seem to be divided into two parts. One lies north and the other south of 22°S. Most deep-water, or eurybathic, species that live in depths greater than 2,000 to 3,000 m, move from one latitude zone to another in the North Pacific Ocean. These comprise 50 to 80% of all transitional species there (fig. 50). The boreal region, northern subtropics, and tropics have many aspects of deep-water foraminiferal fauna in common. The more shallow-water fauna are very different in these regions of the ocean. Most species (50 to 90%) of southern regions of the ocean (south of 22°S), occur in nearby regions. They are relatively shallow-water types and live at depths of less than 2,000 to 3,000 m. In the South Pacific, in addition to the latitudinal similarity of the deep-water agglutinating foraminifera, one can also see a great similarity in the shallow-water fauna. The North Pacific is richer in species than South Pacific. 292 species were found in the boreal and northern subtropical regions, while 224 species occurred in the southern subtropical, notal, and Antarctic regions.

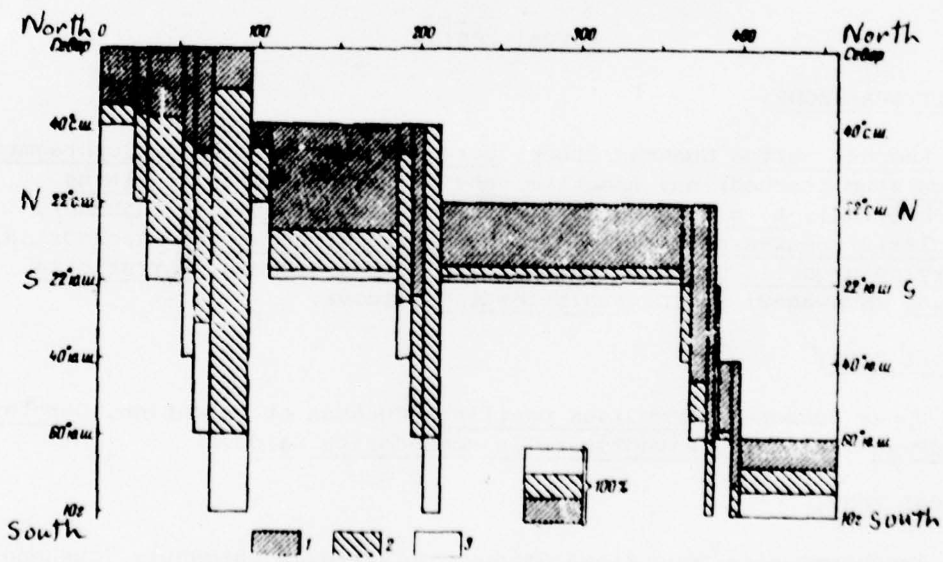


Fig. 50. Quantitative distribution of agglutinating foraminiferal species by latitude and the percentage content (ratio) of deep-water and shallow-water species in each latitude region.
1. Percentage content of species living at depths greater than 2,000 m; 2. less than 2,000 m; 3. above and below 2,000 m.

Study of the vertical and horizontal distribution of foraminiferal species has revealed two different agglutinating foraminiferal faunas from the standpoint of species and genera: shallow-water, warmth-loving fauna that live mainly in the tropical region at depths of less than 500 m, and cold-loving fauna that live in the Antarctic region and in the abyssal zone in all regions of the Pacific Ocean.

All species of agglutinating foraminifera can be divided into three groups. The first, the largest group, consists of latitudinally and bathymetrically stenobiontic species. The second group consists of stenobathic, but latitudinally eurybiontic, species of the Pacific Ocean. The third group consists of latitudinally stenobiontic, but generally eurybathic species. The species composition of this last group is not presented in this work.

Let us discuss the first two groups, which are most important for stratigraphic purposes.

STENOBIONTIC SPECIES

Approximately 210 species can be assigned to the first group. Most of these species are typical of tropical sublittoral and bathyal zones. We will present below the species endemic to the main latitude regions of the Pacific Ocean and confined to specific vertical zones.

Boreal Region

SUBLITTORAL ZONE:

Reophas curtus Cushman subsp. *borealis* Saidova[1]. *Alveolophragmium orbiculatum* Stschedrina, *Ammotium cassis* (Parker) subsp. *inflatus* (Stschedrina), *A. globus* Saidova, *Miliammina agglutinata* (Cushman), *Textularia tenuissima* Earland, *Trochamminula fissuraperta* Stschedrina, *Gaudryina ergoella* Saidova, *Verneuilina advena* Cushman, *Karreriella baccata* (Schwager) subsp. *sublittoralis* Saidova.

BATHYAL ZONE:

Upper Subzone: *Ammodisus pacificus* Cushman et Valentine, *Dorothia subadvena* (Saidova), *Alveologerella comandorica* Saidova.

ABYSSAL ZONE:

Trochamminella mendosiana Saidova, *Listerella antennula* (Cushman).

ULTRA-ABYSSAL ZONE:

Saccorhizo praealta Saidova.

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[1]Descriptions of new species and sub-species will be published as a special report.

NORTHERN SUBTROPICS:

Sublittoral Zone:

Bigenerina nodosaria Orbigny, Carterina spiculotestes (Carter)

Bathyal Zone:

Upper subzone: Cyclammina contorta Pearcey.

Lower subzone: Technitella melo Norman.

Abyssal Zone:

Saccammina socialis Brady, Pelosina rotundata Brady, Reophax spiculifer Brady, R. echinatus Saidova, Cribrostomoides ultimus Saidova, Hemisphaerammina nonbradyi Saidova, Tholosina abyssalica Saidova, Bathysiphon lanosum Saidova.

Ultra-Abyssal Zone:

Ammoscalaria tenuimargo (Brady), Armorella earlandi Saidova, Pelosina morosus Saidova, *Dendrophrya fruticosa* Saidova, Saccorhiza capillacea Saidova, Hyperammina echinata Saidova, Bathysiphon rusticum Folin, Rhizammina transversa Saidova.

NORTHERN SUBTROPICS-TROPICS:

Sublittoral Zone:

Rephax scottii Chaster, R. subfusiformis Earland, R. curtus (Cushman), Cribrostomides trullissatum (Brady), Textularia schencki Cushman, T. lauta Lalicker et McCulloch, T. panamensis Cushman, T. foliacea Heron-Allen et Earland, T. pseudocarinata Cushman, T. ampla Saidova, T. porrecta (Brady), T. sagittula Orbigny, T. pseudotrochus Cushman, Siphitextularia crassisepta (Cushman), Trochammina vesicularis Goes, T. carinata Cushman et McCulloch, Gaudryina rugulosa Cushman, G. pauperata Earland, G. arenaria Galloway et Wissler, G. trullissata Todd, G. subglabrata Cushman et McCulloch, Verneuilina pseudopusilla Saidova, Textulariella pacifica Cushman, T. nivea Saidova, Chrysalidinella spectabilis Cushman et McCulloch, Rudigaudryina inepta Cushman et McCulloch, Placopsilina bradyi Cushman et McCulloch, tropicus Saidova, R. depressus Natland, Discammina planissima Cushman.

Bathyal Zone:

Upper subzone:

Cribrostomoides veleronis (Cushman et McCulloch), Cyclammina ataensis Saidova, C. sacharifera Saidova, Cribrogoessella pacifica Cushman et McCulloch.

Lower subzone: Hormosina resina Saidova, H. ovicula Brady.

Abyssal Zone:

Psammosphaera fallax (Rhumbler), Jaculella acuta Brady, Hyperammina subnodosa Brady, Hormosina adunca (Brady), H. saccaminae (Rhumbler), Pseudonodosinella nodulosa (Brady), Nodelum membranacea (Brady), N. bibulatum (Egger), Saccorhiza echinata Saidova.

NORTHERN SUBTROPICS - SOUTHERN SUBTROPICS:

Ultra-Abyssal Zone: Tholosino irregularis Rhumbler.

TROPICS:

Sublittoral Zone:

Astrorhiza hancocki Cushman et McCulloch, A. crassatina Brady, Hyperammina spiculifera Lacroix, Sagenina divaricatus Cushman, S. frondescens (Brady), S. ramulosa Cushman, Proteonina ovata Cushman, Pilulina ovata Cushman, Webinella hemisphaerica (Jones, Parker et Brady), Haplophragmoides grandiformis Cushman, Ammobaculites flexus Saidova, Ammoastuta inepta (Cushman et McCulloch), Miliammina fusca (Brady), Silicosigmoilina arenaria (Brady), Textularia scrupula Lalicker et McCulloch, T. plaga Lalicker et McCulloch, T. semialata Cushman, T. goesi Cushman, T. fistulosa (Brady), Bolivinopsis bulbosa (Cushman), Rotaliammina mayori Cushman, Carterina fulva Cushman, Nouria harrisii Heron-Allen et Earland, Gaudryina convexa Cushman, G. jarvisi Cushman, G. attenuata Chapman, Clavulina difformis (Brady), C. pacifica Cushman, Textulariella nivea Saidova, Goesella parva Cushman et McCulloch, Liebusella bradyi (Cushman), Chrysalidinella dimorpha (Brady), Bdelloidina aggregata Carter, Bigenerina digitata Orbigny, B. irregularis Phleger et Parker, Textularia obbreviata Orbigny, T. lytostrota (Schwager), T. ramosa Lalicker et McCulloch, Siphotextularia albatrossi (Cushman), Trochammina helicoideum (Goes), T. nana (Brady), Trochamminella sphaeroidiniformis (Brady), Gaudryina rugulosa Cushman, G. robusta Cushman, Clavulinoides indiscreta (Brady), C. orientalis Cushman, Verneuilina polystropha (Reuss), V. tessera Saidova, V. affixa Cushman, V. pusil'a Goes, Dorothia paupercula (Cushman), D. scabra (Brady), Listerella bradyana Cushman.

132 Bathyal Zone:

Upper subzone:

Critionina lens Goes, *Bathysiphon filiformis* Sars, *B. argenteus* Heron-Allen et Earland, *Marsipella gigantea* Cushman, *Saccammina catenulata* (Cushman), *Thurammina papiracea* Brady, *Verrucina rudis* Goes, *Dendrophrya atenuata* Cushman, *D. ramosa* Cushman, *Reophax scorpiurus* Montfort, *R. horridus* Cushman, *R. bilocularis*? Flint, *Hormosina ovaliformis* Cushman, *H. vorax* Saidova, *H. distans* Brady subsp. *tropica* Saidova, *Pseudonodosinella insecta* (Goes), *Sphaerammina ovalis* Cushman, *Ammosphaerulina adhaerens* Cushman, *Glomospira charoides* (Jones et Parker) subsp. *curti* Saidova, *Gl. tracta* Saidova, *Tolypammina vagans* (Brady), *Cribrostomoides emaciatum* (Brady) subsp. *exilis* Saidova, *Cyclammina paucilloculata* Cushman, *C. maniensis* Saidova, *Haplophragmium madefactus* Saidova, *Silicosigmoilina venia* Saidova.

Lower subzone:

Proteonina fusiformis Williamson, *Thurammina erinacea* Goes, *Aschemonella armatus* Goes, *Nousina agassizii* Goes, *Lituotuba lituiformis* (Brady), *Siphotextularia aperturalis* Cushman, *Trochamminello soldanii* (Earland).

Abyssal Zone:

Saccorhiza profunda Saidova, *Hormosina carpenteri* Brady, *H. casa* Saidova, *Nodelum parkum* Saidova, *Glomospira piscicula* Saidova, *Cribrostomoides coinulus* Saidova, *Trochammina praealta* Saidova, *Schenskiella* sp. 6, *Protobotelina stschedrinai* Saidova.

Ultra-Abyssal Zone:

Bathysiphon bougenwillensis Saidova, *Rhabdammina bougenwillica* Saidova, *Tholosina* sp. 2, *Ammobaculites obnoxius* Saidova, *Trochamminella cribrotrochammina* Saidova.

TROPICS-SOUTHERN SUBTROPICS:

Bathyal Zone:

Upper subzone: *Bathysiphon solomonensis* Saidova, *Cyclammina pusilla* Brady subsp. *compresa* (Cushman), *Gaudryina* sp. 1.

Abyssal Zone: *Rhizammina algaeformis* Brady.

SOUTHERN SUBTROPICS:

Abyssal Zone: *Aschemonella ramuliformis* Brady.

Ultra-Abyssal Zone: *Pelosina cilindrica* Saidova, *Hyperammina pseudoelongata* Saidova.

Notal Region

Sublittoral Zone: Dendronina limosa Heron-Allen et Earland, D. antarctica Heron-Allen et Earland, Rheophax pseudodistans (Cushman), Siphotextularia obesa Parr.

Bathyal Zone:

Upper subzone: Vulvulina careolus Orbigny.

Antarctic Region

Sublittoral Zone:

Reophax advenus Saidova, Protoschista euneta Jensen, Turrtellella shoneana (Siddall), Dorothia paupercula (Cushman), Siphotextularia arenacea (Heron-Allen et Earland), Trochamminella lobatula var. arenacea (Heron-Allen et Earland), Trochammina wiesneri Parr, Dendronina humilis (Heron-Allen et Earland).

Bathyal Zone:

Upper subzone: Hormosina distans Brady subsp. antarctica Saidova, Pseudonosinella carotis Stschedrina, Miliammina oblonga Heron-Allen et Earland, Textularia variabilis var. Arenacea Heron-Allen et Earland.

Lower subzone: Haplophragmoides soldani var. Heron-Allen et Earland.

133 STENOBATHIC SPECIES

The second group consists of about 105 species. They occur in different latitude regions, but always at the same depths, i.e. they are stenobathic species. They are presented below by the main vertical (depth) zones of the ocean.

Sublittoral Zone:

Pelosina variabilis Brady, Cribrostomoides columbiensis (Cushman), Haplophragmium notalnus Saidova, Textularia hauerii Orbigny, T. conica Orbigny, T. vola Lalicker et McCulloch, T. lancea Lalicker et McCulloch, T. fistulosa (Brady), Siphotextularia heterostoma (Heron-Allen et Earland), Trochammina squamiformis Cushman et McCulloch, T. rotaliformis Wright, T. dellettae Thalman, T. pacifica Cushman, T. discorbis Earland, T. charlottensis Cushman, Goesella flintiana (Cushman).

Sublittoral-Bathyal Zone:

Upper subzone: Recurvoides contortus Earland subsp. sublittoralis Saidova, Trochammina fusca (Williamson).

Bathyal Zone:

Upper subzone: Psammosphaera fusca Schultze, Reophax kerguelensis Parr, Hormosina globulifera Brady, Cribrostomoides bradyi Cushman, Ammobaculates arenaria Natland, Silicosigmoilina schlumbergeri (Silvestri), S. celata (Costa), Textularia occidentalis (Cushman), Vulvulina arenacea (Bagg), Cribrogoesella bradyi bradyi Cushman.

Upper subzone-Lower subzone:

Ammomarginulina ensis Wiesner, Bolivinopsis annectens (Parker et Jones), Trochammina globigeriniformis (Parker et Jones) subsp. curtus Saidova, Trochamminella imperialis Saidova, Karreriella cubensis Cushman et Bermudez, K. bradyi Cushman, K. novangliae (Cushman), Listerella primaeva (Cushman).

Lower subzone:

Marsipella cylindrica Brady subsp. attus Saidova, Hormosina spasmina Saidova, H. guttifera (Brady), Proteonina testacea (Flint), Cyclammina orbicularis Brady, Ammomarginulina fontiensis (Terquem), Ammocibicides proteus Earland.

Lower Bathyal subzone:

Rhabdammina abbyssorum Sars, Bathysiphon rufus Folin, Jaculella acuta Brady, Reophax dentalimformis Brady, Hormosina distans distans Brady, Glomospira charoides charoides (Jones et Parker), Ammodiscus profundissimus Saidova, Recurvoides contortus Earland subsp. gurgitis Saidova, Cribrostomoides sphaeriloculum (Cushman), C. arctica (Parker), Cyclammina bradyi Cushman, C. pusilla Brady, C. concellata Brady, Adercotryma glomerata (Brady) subsp. abyssorum Saidova, Ammobaculities subfusiformis Saidova, Spirolacammina tenuis (Czjzek), Trochammina tumefacta Saidova, Dorothia curta (Cushman), Cribrogoesella bradyi Cushman subsp. alta Saidova, Eggerella rotundata Karrer.

Lower Bathyal-Abyssal subzone:

Proteonina longicolis Wiesner, Hyperammina elongata Brady, Hormosina aetheria Saidova, Cribrostomoides canariensis (Orbigny) Normanina elongata Saidova.

Abyssal Zone:

Rhizammina alta Saidova, Protobelina pacifica Saidova, Pelosina arborescens Pearcey, Bathysiphon arenacea Cushman, Psammosphaera manus Saidova, Hormosina normani Brady, Nodosinum moniliforme Stschedrina, Haplophragmoides bradyi Robertson subsp. profundum Saidova, Discammina emaciata (Brady), subsp. opima Saidoya, Cribrostomoides anomalinoides

(Wiesner). *C. subglobosum* (Sars) subsp. *praealtum* Saidova, *C. profundum* Saidova, *Recurvoides politus* Saidova, *Ammobaculites echinatus* Saidova, *Ammomarginulina foliacea* (Brady) subsp. *abyssorum* Saidova, *Siphotextularia catenata* (Cushman), *Trochammina globulosa* Cushman, *T. subglabra* Saidova, *T. subnana* Saidova, *T. abyssorum* Saidova, *Trochaminella trochamminiformis* Saidova, *Verneuilina propinqua* Brady, *Listerella occidentalis* (Cushman).

134 Abyssal-Ultra Abyssal Zone:

Rhabdammina linearis Brady, *Sorosphaera abyssorum* Saidova, *Hormosina ovicula* Brady, *H. casus* Saidova, *Pseudonodosinella subbacillaris* Stschedrina, *P. pseudonodulosa* Stschedrina, *Spiroplectammina biformis* (Parker et Jones) subsp. *surtida* Saidova, *Trochammina globideriniformis* (Parker et Jones) subsp. *alta* Saidova, *Trochamoninella paradoxa* Stschedrina, *Pseudoplectina apicularis apicularis* (Cushman), *Aschemonella scabra* Brady.

Ultra-Abyssal Zones:

Normanina ultrabyssalica Saidova, *Dendrophyro kermandekensis* Saidova.

ZONE		REGION				Species encountered in all zones	TOTAL
		boreal	tropical	notal	Antarctic		
Sublittoral		10	61	4	8	17	100
Bathyal	Upper	3	54	1	4	10	72
	Lower	-	9	-	1	6	16
Abyssal	Proper	2	22	-	-	22	46
	Ultra Abyssal	1	16	-	-	2	19
TOTAL		16	162	5	13	-	-

Table 21. Number of endemic agglutinating foraminiferal species in the Pacific Ocean.

Summarizing the data obtained on the endemic aspect of agglutinating foraminiferal species of the Pacific Ocean (table 21), it can be seen that the largest number of endemic species are in the tropical region, but they generally decrease with depth.

Distribution of Genera of Agglutinating Foraminifera

The agglutinating foraminifera of the Pacific Ocean belong to 100 different genera, which can be divided into 2 main groups: stenobiontic and relatively eurybiontic.

The first group is the more numerous and consists of latitudinally or vertically stenobiontic species confined to one of the zones - boreal, tropical, notal, or Antarctic - as well as to some vertical zones - sublittoral, bathyal, or abyssal. In the Pacific Ocean, most of these genera are endemic to the tropical region, and most of them were found only in the tropics.

They are: *Neusina*, *Hospitella*, *Sphaerammina*, *Ammosphaerulina*, *Lituotuba*, *Crithionina*, *Pilulina*, *Webinella*, *Tholosina*, *Verrucina*, *Sagenina*, *Ammoastuta*, *Ammoscalaria*, *Tawitawia*, *Rotaliammina*, *Carterina*, *Verneuilina*, *Clavulina*, *Clavulinoides*, *Pseudoclavulina*, *Schenskiella*, *Tritaxilina*, *Liebussella*, *Bdeloidina* - a total of 24 genera. The remaining genera occurred in the tropics and subtropics: *Saccammina*, 135 *Technitella*, *Jaculetta*, *Hyperamminoides*, *Dendrophrya*, *Aschemonella*, *Ammofrondicularia*, *Haplostiche*, *Nodelum*, *Tolypammina*, *Trochamminoides*, *Bigenerina*, *Tritaxis*, *Chrysalidinella*, *Placopsilina*. (15 genera) Four endemic species occurred in the boreal region: *Alveolophragmium*, *Ammotium*, *Trochamminulla*, *Alveogerella*; 2 in the notal zone-*Dendronina*, *Plectotrochammina*. The genus *Alveolophragmium* seems to be bipolar.

From the above material it is clear that most agglutinating genera are relatively warm-water types and live in the tropics. The following genera can be considered as endemic in the sublittoral zone. *Pilulina*, *Hoplostiche*, *Turritellella*, *Alveolophragmium*, *Ammotium*, *Ammoscalaria*, *Tawitawia*, *Trochamminulla*, *Rotaliammina*, *Carterina*, *Nouria*, *Liebusella*, *Chrysalidinella*, *Placopsilina*, *Bdeloidina*, *Webinella*, *Dendronina*, *Sagenina*, *Protoshista*, *Ammofrondicularia*.

The following species should be considered endemic to the upper bathyal subzone (depths to 1,500 to 2,000 m): *Verrucina*, *Sphaerammina*, *Pseudoclavilina*, *Alveologerella*; species endemic to the lower subzone are: *Crithionina*, *Neusina*, *Lituotuba*, *Plectotrochammina*, *Ammocibicides*.

The abyssal zone is characterized by the fewest endemic genera: *Saccammuina*, *Hyperamminoides*, *Aschemonella*, *Nodelum*. There is also a group of genera (*Verneuilina*, *Clavulina*, *Textulariella*, *Goesella*, *Tritaxilina*) representatives of which live in the eulittoral zone and upper bathyal subzone. Representatives of *Technitella* live in the entire bathyal zone, and *Spiroplectammina* live in the lower bathyal subzone and in the abyssal zone. Such structuring of the agglutinating foraminiferal genera shows that most of them are of the warm-water type and the number of endemic genera decreases as depth increases (table 22).

Zone		Region				Species found in all latitudes	TOTAL
		boreal	tropical	notal	Antarctic		
Sublittoral		3	13	2	2	–	20
Bathyal	Upper	1	5	–	–	4	10
	Lower	–	3	–	1	1	5
Abyssal		–	3	–	–	1	4
TOTAL		4	24	2	3	6	39

Table 22. Number of endemic agglutinating genera of foraminifera in the Pacific Ocean.

The second group consists of relatively eurybiontic genera found in all latitudes and at different depths.

The lower boundary of their habitat in most cases reaches to maximum ocean depths, while the upper boundary is higher or lower depending on salinity and water temperature, or oxygen content. The upper habitat boundary of many genera of these groups is located at 2,000 to 3,000 m depths in high latitudes and rises alowly to 500 to 1,000 m in the equatorial region, where the water salinity is within the same limits (34.5 to 34.7‰) as found at lower depths in higher
136 latutudes. Such genera, which are highly sensitive to salinity, are:

Bathysiphon, Psamosphaera, Proteonina, Hyperammina, Ammologena, Ammomarginulina, Silicocigmoilina, Spirolocammina, Textularia, Ammobaculites, Globotextularia, Tritaxis, Cystammina, Dorophia, Cribogoesella, and Gandryina. These genera are stenohaline.

The other part of the genera of the group discussed is more sensitive to the water temperature. There upper habitat boundary is at depths of less than 200 to 500 m in high latitudes and gradually descends to more than 1,000 m as it moves farther into the tropical region. Lower water temperatures of 0 to 5°C favor these genera; they avoid regions with mean water temperature greater than 5°C, consequently, they can be classified as stenothermic organisms, Recurvoides, Adercotryma, Trochammina, Eggerella, Listerella belong to the latter genera.

Some representatives of this group, in addition to temperature, also respond to the oxygen content of water. Their upper habitat boundary is at depths less than 200 to 500 m in the Antarctic region, and progressively farther north to boreal regions they gradually descend to 2,000 to 3,000-m depths. In the boreal region, these genera cannot rise higher within the low temperatures favorable to

them, because a minimum oxygen layer with oxygen contents less than 1.5 to 2.0 ml/l lies at depths greater than 2,000 m. These genera are as follows: Sorosphaera, Saccorhiza, Hormosina, Pseudonodosinella, Nodosinum, glomospirella, and Trochamminella. It seems that they can be classified as stenoxigenous organisms.

The percentage and arithmetic mean content of shells of some genera found in large numbers in many latitude regions of the ocean was calculated. The percentage content was determined relative to all shells of benthic foramifera found in the sediment. This method made it possible to determine the most favorable habitat conditions of the genera.

In the boreal region the genus Bathysiphon occurred at depths greater than 2,000 m in quantities of 5 to 8 shell specimens, which comprised 3 to 7% in this region. In tropical regions, shells of this genus were found at depths greater than 400 m. The largest numbers of these shells (17 spcm) were found at 2,000 to 3,500 m depths at water temperatures of 1.5 to 2°C and salinities of 34.62 to 34.68 ‰. But the greatest percentage of shells of this genus in the total foraminiferal shell content was 10% at 3,500 to 6,500 m depths.

In the boreal region, the genus Sorosphaera occurred at depths greater than 2,500 m. The largest number of specimens (65 spcm) was found at depths of 3,000 to 4,000 m, where it formed the largest percentage (15%) of the total content of foraminifera. Water temperatures of 1.43 to 1.59°C and salinities of 34.65 to 34.76 ‰ characterize these depths. In tropical regions this genus occurs at depths exceeding 900 m. The greatest number of Sorosphaera specimens (160) occurred in this region at depths less than 6,500 m, where it comprises 75%. The water temperatures here are less than 1.7°C and salinity is 34.70 to 34.73 ‰. In the Antarctic region this genus rises to 500 m. The greatest number of specimens (10 spcm) occur at 500 to 1,000 m depths, in water temperatures of -1.5 to -1°C, and at salinities of 34.7 to 34.76 ‰.

In all regions, genus Psammosphaera was found down to maximum depths of 6,000 m. It occurred in largest numbers (60 spcm) at depths of 2,500 to 3,500 m in Antarctic regions in water temperatures of 0.3°C, and salinities of 34.69 to 34.70 ‰ (60 spcm). The greatest percentage of shells of this genus (8%) occurred at depths greater than 3,500 m.

In all regions, the genus Hormosina (S.L.) (of the species type H. distans) occurred at depths less than 5,500 m, but in the boreal region (it was found) below 1,750 m, in the tropics - below 1,000 m,
137 and in the Antarctic - below 100 m. The largest number of specimens (60 spcm) occurred in the Antarctic region at depths less than 750 m, water temperatures of -1.94 to 1°C, and salinities of 34.5 to 34.7 ‰,

where they comprise approximately 8%.

Hormosina (J.S.) (of the species type *H. normani*) was found in all regions. The greatest number of specimens were at depths of 4,000 to 6,500 m (up to 30 spcm), where it comprises 30%. At these depths, the water temperature is 1.44 to 1.53°C and salinity is 34.6 to 34.74 ‰.

The greatest quantity of *Pseudonodosinella* specimens (approximately 50 spcm) was found in boreal regions at 3,000 to 6,500 m depths, in water temperatures of 1.43 to 1.59°C, and in salinities of 34.60 to 34.76 ‰. Specimens of these genus formed the greatest percentage (55%) at depths exceeding 6,500 m. Representatives of this genus are also numerous in the Antarctic at depths of 500 to 1,000 m, water temperatures of -1.5 to 1°C, and salinities of 34.70 to 34.76 ‰, but their shells do not comprise large percentages there. In the tropical region, at depths greater than 6,500 m, shells of this genus comprise 45% of all shells found.

The genus *Reophax* is represented by large numbers of shells (40 spcm) in the notal region at depths of 200 to 500 m, water temperatures of 6 to 10°C, and salinities of 34.4 to 34.6 ‰. However, shells of this genus comprise only 1 to 2%. In the Antarctic region, they are numerous (about 25 spcm) at depths less than 500 m, and the percentage of shells increases to 8 to 10% there. At these depths, the water temperature is from -1.85 to 0°C, and salinity is 34.5 to 34.7 ‰.

The greatest quantity of genus *Nodosinum* specimens occurred at 4,000 to 6,500 in depths in the boreal region and at depths of 3,500 to 6,000 m in the tropical region. Shells of this genus comprise the largest percentage in the tropics at depths exceeding 6,500 m. Water temperatures of 1.44 to 1.53°C and salinities of 34.60 to 34.74 ‰ are favorable for this genus.

Genus *Haplophragmoides* is represented by a large number of shells (20 spcm) in the tropical region, at depths of 500 to 1,000 m, water temperatures of 5.5 to 7.0°C, and salinities of 34.1 to 34.6 ‰. In the remaining regions, representatives of this genus occur as individual specimens.

Genus *Cribrostomoides* occur more frequently and in greater quantities than *Haplophragmoides*. It was found at 3,000 to 6,500 m depths (45-58 spcm, comprising about 20%), water temperatures of 1.43 to 1.59°C and salinities of 34.60 to 34.76 ‰. This genus is represented by even larger numbers of shells in the notal region at depths of 3,500 to 6,500 m (70 spcm comprising 1%), and salinity of 34.67 to 34.71 ‰. In the Antarctic, the greatest number of *Cribrostomoides* 80 spcm, comprising 1%) occurred at depths of 2,500 to 3,500 m, water temperatures of 0.2 to 0.5°C, and salinities of 34.66 to 34 ‰.

Consequently, representatives of genus *Cribrostomoides* are more typical of cold, deep-water than species of genus *Halophragmoides*.

Large numbers of *Cyclammina* genus specimens were found at depths below 3,000 m in the boreal region (15-25 spcm, comprising 5 to 10%) and at depths of 3,500 to 6,500 m in the tropic region (17 spcm, comprising 15%), at water temperatures of 1.43 to 1.75°C and salinities of 34.40 to 34.76‰. The greatest quantity of *Cyclammina* shells occurred in the Antarctic region (40 spcm, comprising 20%) at 1,000 to 3,500 m depths, water temperatures of -1 to 1°C, and salinities of 34.66 to 34.77‰.

Genus *Recurvoides* shells occurred in large numbers at depths exceeding 3,000 m in the boreal region (38-55 spcm, comprising 15 to 40%) and at depths greater than 6,000 m in the tropica (170 spcm, comprising 20%), at water temperatures of 1.43 to 1.7°C and salinities of 34.60 to 34.73‰, as well as at depths less than
138 2,000 m in the Antarctic region (35-42 spcm, comprising 15%), water temperatures of -1.0 to 1.5°C, and salinities of 34.5 to 34.7‰.

The greatest quantities of genus *Adercotryima* specimens were found in the boreal region at depths less than 500 m (40 spcm, comprising 17%), water temperatures of 2 to 4°C, and salinities of 33.5 to 34.0‰; and at 4,000 to 6,500 m depths (37 spcm, comprising 15%0, water temperatures of 1.44 to 1.53°C, and salinities of 34.60 to 34.74‰. In the Antarctic region approximately 60 spcm 1 g occurred at depths of 2,500 to 3,500 m, a water temperature of 0.3°C, and salinities of 34.69 to 34.70‰.

Genus *Ammobaculities* occur at depths greater than 300 to 500 m in the Pacific Ocean. The largest number of specimens (36 spcm, comprising 1%) occur at depths of 2,000 to 3,500 m, water temperatures of 1.5 to 2°C, and salinities of 34.62 to 34.68‰ in the tropical region, and at 3,500 to 6,500 m depths, water temperatures of 0.7 to 1.5°C, and salinities of 34.67 to 34.71‰ in the notal region (300 spcm, comprising 1%). In the boreal region, this genus lives in large quantities at 4,000 to 6,500 m depths (23 spcm, comprising 7%), water temperatures of 1.44 to 1.53°C, and salinities of 34.60 to 34.74‰.

Genus *Haplophragmium* was found in the notal region in largest numbers at depths less than 500 m (121 spcm, comprising 1%), water temperatures of 8 to 10°C, and salinities of 34.5 to 34.6‰. Consequently, compared with genus *Ammobaculities*, *Haplophragmium* is more adapted to warm and shallow water.

Genus *Textularia* is represented by an enormous quantity of specimens at depths less than 500 m (500 spcm, comprising 10%), water temperatures of 19 to 28°C, and salinities of 34.5 to 35 ‰; in the

tropics; and at water temperatures of 8 to 10°C and salinities of 34.25 to 34.75 ‰ in the notal region (5,775 spcm, comprising 35%).

Genus Miliammina was found (127 spcm, comprising 1%) in the tropical region at depths of 2,500 to 3,500 m, water temperatures of 1.5 to 2.0°C, and a salinity of 34.7 ‰. In the remaining region this genus occurred as individual specimens.

The largest numbers of genus Trochamina occur in the boreal region at depths exceeding 4,000 m (4-100 spcm, comprising 1-40%), water temperatures of 1.44 to 1.53°C, and salinities of 34.60 to 34.74 ‰, and in the notal region (200 spcm, comprising 1%) at depths of 3,500 to 4,000 m, water temperature of 1°C, and salinity of 34.7 ‰.

Genus Trochamminella is most numerous in the boreal region (30-112 spcm, comprising 4-58%) at the same depths and water temperatures as Trochammia. In the tropical region, especially large quantities of Trochamminella were found at depths greater than 6,500 m (35 spcm, comprising 49%) water temperature of approximately 1.7°C, and salinities of 34.70 to 34.73 ‰.

The greatest number of shells of genus Listerella occurred at depths of 3,000 to 4,000 m, water temperatures of 1.43 to 1.59°C, and salinities of 34.65 to 34.76 ‰ in the boreal region (40 spcm, comprising 4%); and at depths of 2,000 to 3,000 m, water temperatures of 0.2 to 0.5°C, and salinities of 34.66 to 34.77‰ in the Antarctic.

Genus Gaudryina is abundant in the tropica (123 spcm, comprising 1%) at depths less than 500 m and at the same water temperatures and salinity as genus Textularia.

The largest number of specimens (155 spcm, comprising 1%) of genus Eggerella occur in the boreal region at depths of 2,000 to 3,000 m, water temperatures of 1.72 to 1.90°C, and salinities of 34.6 to 34.7‰; at depths of 3,000 to 4,000 m, water temperature of 1°C, and salinity of 34.7‰ in the notal region (500 spcm, comprising 2%); and at depths of 4,000 to 5,000 m, water temperatures of 1.30 to 1.5°C, and salinities of 34.70 to 34.72 ‰ in the tropical region (46 spcm, comprising 1%).

Large numbers of genus Karreriella (114-132 spcm, up to 4%) occurred in the boreal region at depths of less than 1,000 m, water temperatures of 2 to 4°C, and salinities of 34.00 to 34.28 ‰; in the tropics (55 spcm, 2 to 3%) at depths of 500 to 1,000 m, water temperatures of 4.5 to 5.5°C, and salinities of 34.5‰; and in the notal zone at depths of 1,000 to 2,000 m, water temperatures of 2.0 to 2.5°C, and salinities of 34.6 to 34.7 ‰.

Distribution of Orders of Agglutinating Foraminifera

Contemporary Pacific Ocean foraminifera with agglutinated shells belong to the orders Astrorhizida, Ammodiscida, Textulariida, and Ataxophragmiida.

The following features of the distribution of various orders by depth are typical of the Pacific Ocean as a whole. At depths less 400 m, species of the orders Textularia (20-26%) and Ataxophragmiida (36-42%) predominate; at depths of 400 to 1,500 m, species of the orders Astrorhizida (29-37%), Ammodiscida (25-32%), and Ataxophragmiida (23-36%) predominate; while at depths exceeding 1,500 m representatives of the orders Astrorhizida (37-41%) and Ammodiscida (34-42%) orders largely predominate. The percentage content is given relative to the quantity of all species of agglutinating foraminifera (table 23). From the values presented it can be seen that the most highly organized and youngest foraminifera belonging to the orders Textulariida and Ataxophragmiida are represented by a few forms at shallow depths and higher temperatures. At great depths in the Pacific Ocean with constant low temperatures, the groups belong mainly to the most ancient and primitive representatives of agglutinating foraminifera of the orders Astrorhizida and Ammodiscida.

The relatively high percentage (17-22%) of species of the order Ataxophragmiida at depths exceeding 1,500 m, depends mainly on the presence, at great depths, of a large number of species belonging to the genera Trochammina and Trochaminella. Species of these genera comprise 60% of the entire deep-water fauna of the order Ataxophragmiida. It seems, that these genera should be transferred from Ataxophragmiida to the order Ammodiscida. The same also pertains to the genera Globotextularia and Cystammina.

In the Pacific Ocean, the order Astrorhizida is represented by 50 genera and 239 species. In different regions of the ocean, the order is characterized by different numbers of species and foraminiferal shells. In the boreal region, this order is represented by the largest number of shells and species at depths greater than 2,750 m. In the northern subtropics, representative of this order are most numerous at 2,250 to 7,000 m depths. At depths less than 2,250 m, the number of the representatives is 4 to 5 times smaller. In the tropics, species of the order Astrorhizida occurred in large numbers at all depths, but the greatest number were at depths of 500 to 2,000 m. The water temperature in this region is 3 to 10°C. These species generally are represented by a few shells, excluding 2,000 to 2,500 m depths, where their number increases. In the notal region and in the southern subtropics, this order is characterized by small species composition represented by few shells. In the Antarctic, the largest number of species occurred at 400 to 2,750 m depths, while the greatest quantity of shells occurred at depths of 300 to 1,500 and 2,500 to 3,500 m.

Depth (m)	Order			
	Astrorphizida	Animodiscida	Textulariida	Ataxophragmiida
0-50	16.0	20.0	26.0	38.0
50-100	14.6	20.4	25.2	39.8
100-200	17.2	21.8	23.6	36.4
200-300	16.5	20.7	20.7	42.1
300-400	14.9	21.5	21.5	42.1
400-500	22.1	23.0	18.0	36.9
500-750	29.7	25.6	12.4	32.3
750-1000	31.2	29.6	9.6	29.6
1000-1250	37.7	32.1	7.3	22.9
1250-1500	37.0	32.4	7.4	23.2
1500-1750	37.7	34.6	5.8	21.2
1750-2000	41.0	35.0	2.0	22.0
2000-2250	39.1	35.9	3.3	21.7
2250-2500	38.2	37.1	2.0	22.7
2500-2750	36.2	40.9	1.0	21.9
2750-3000	37.7	39.4	0.9	22.0
3000-3250	40.0	36.4	2.7	20.9
3250-3500	41.5	37.5	2.7	17.9
3500-4000	41.1	38.3	1.9	18.7
4000-4500	40.6	39.6	2.0	17.8
4500-5250	39.8	39.8	1.1	19.3
5250-6000	39.1	40.2	1.1	19.6
6000-8000	30.3	42.4	6.1	21.2
8000-10000	30.3	42.4	6.1	21.2

Table 23. Quantity of various agglutinating species by orders at various depths in the Pacific Ocean (in % of total quantity of agglutinating species).

The water temperature at these depths in this region is less than 2°C.

From the above material it follows that temperatures below 3°C are the most favorable for representatives of the order Astrorhizida. At such temperatures, these representatives are characterized by large quantities of shells and many species at the whole range of depths. At temperatures of 3° to 10°C, this order is represented by many species and few specimens (fig. 51), while at temperatures above 10°C, it is represented by few species and few shells. Consequently, the order Astrorhizida, as a whole, are cold-water fauna.

The order Ammodiscida is represented in the Pacific Ocean by 21 genera and 131 species. Most species of this order were found in the boreal region at 2,500 to 7,000 m depths. Many shells of species of the order Ammodiscida occurred at depths of 2,000 to 7,000 m. In the northern subtropics, many species occurred at depths exceeding 2,250 m, while most shells were found below 1,500 m. In the tropics, the greatest number of species of this order occur at depths of 750 to 6,000 m, while most shells and species were at depths below 3,000 m. Overall, this zone is characterized by few species. In the notal region, the total number of species is insignificant at all depths, but at depths of 100 to 3,000 and 1,000 to 1,500 m they are represented by many shells. The water temperature here is of the order of 5° to 10°C. In the Antarctic region, the number of species increases to two or three times those of the two preceding regions, especially at depths greater than 4,000 m. These species are represented by large quantities of shells at all depths, but most of them are found between 2,500 and 4,000 m (fig. 52).

In the Pacific Ocean, the distribution pattern of the order Astrorhizida is also typical of the order Ammodiscida. Water temperatures of less than 3°C are most favorable for latter order, and it is represented by a large number of species and specimens. At temperatures of 3° to 10°C it is characterized by many species and few specimens. And, finally, at water temperatures above 10°C, one usually finds individual specimens of a few species of this order.

The order Textulariida is represented in the Pacific Ocean by 9 genera and 62 species in the Pacific.

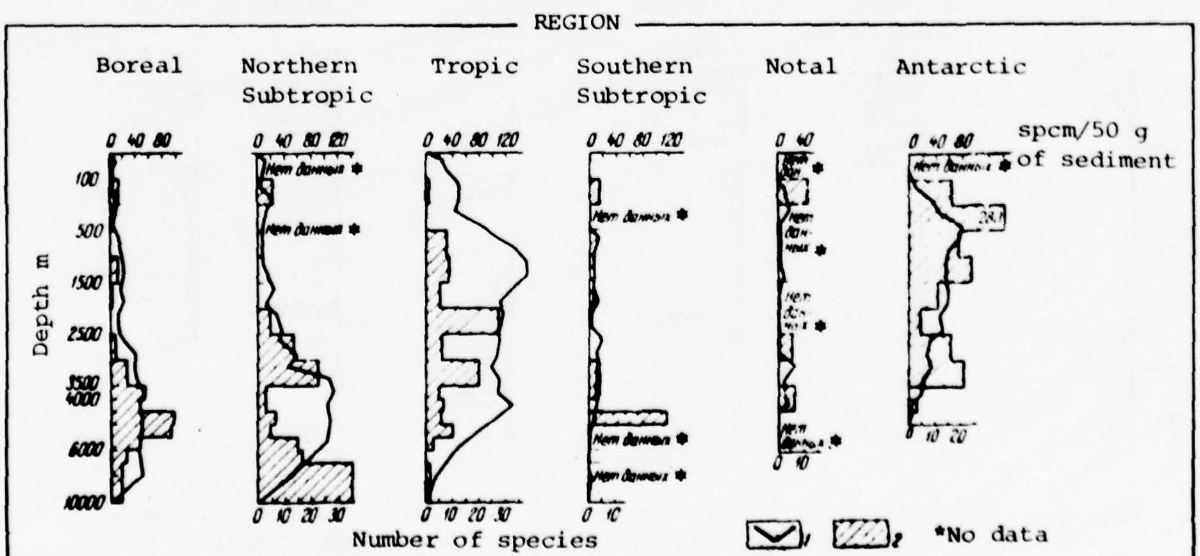


Fig. 51. Variation with depth of the number of species and specimens of the order Astrorhizida in different zoogeographic regions of the Pacific Ocean.

1. number of species; 2. arithmetic mean content of specimens in 50 g of sediment.

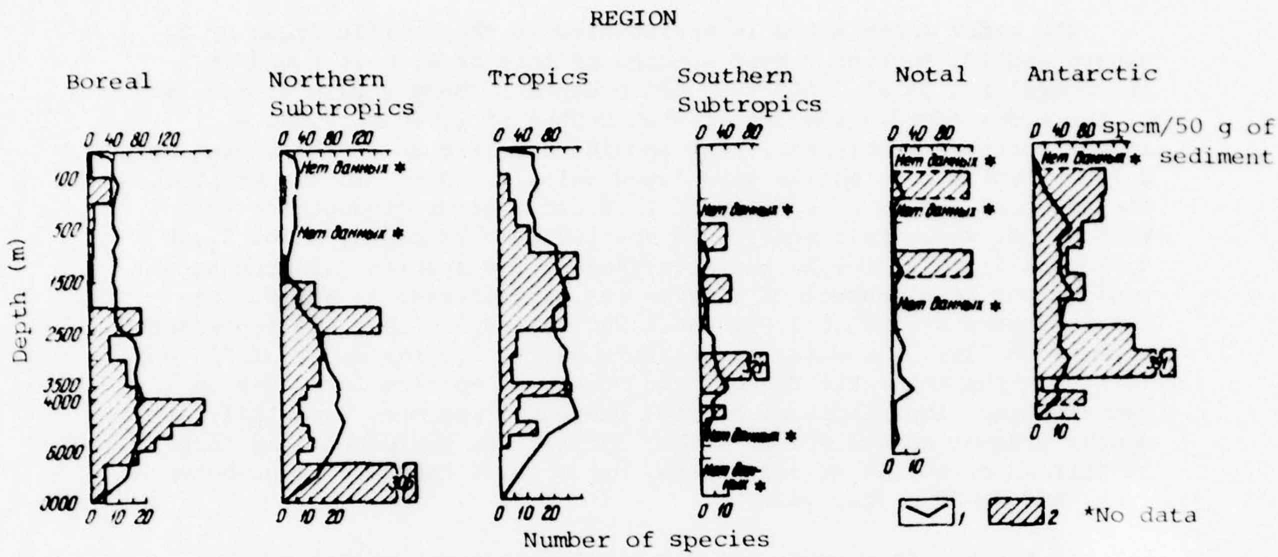


Fig. 52. Variation with depth of the number of species and specimens of the order Ammodiscida in different zoogeographic regions of the Pacific Ocean.

1. number of species; 2. average arithmetic mean content of specimens in 50 g of sediments.

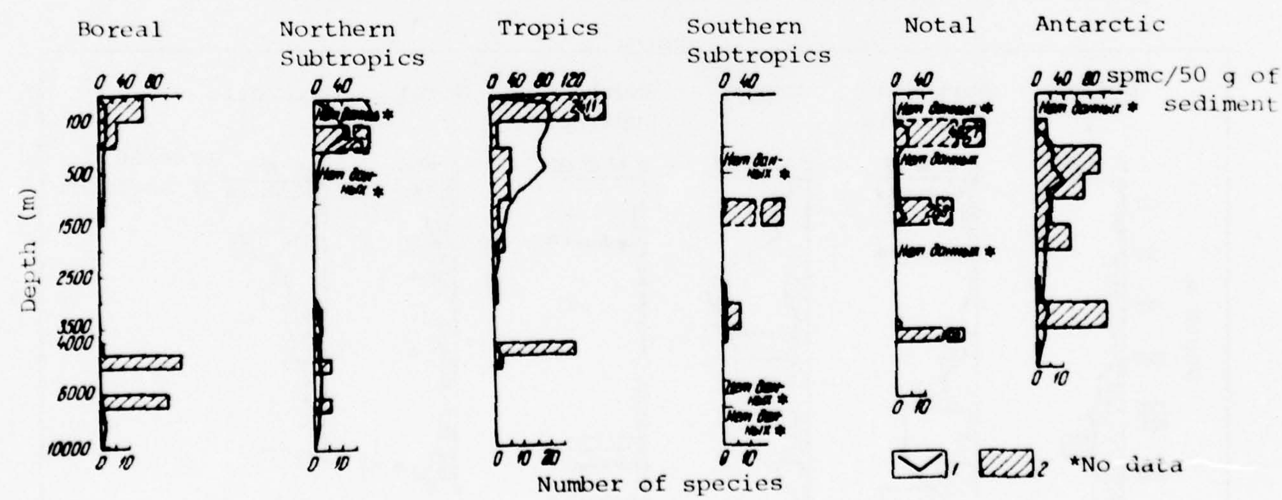


Fig. 53. Variation with depth of the number of species and specimens of the order Textulariida in different zoogeographic regions of the Pacific Ocean.

1. number of species; 2. average airthmetic mean content of specimens in 50 g of sediment.

Typical representatives of this order in the boreal region are characterized by the small numbers of species and specimens. In the northern subtropics, at depths of less than 300 m, they are represented by many species and specimens. Water temperatures of 10° to 25°C and salinities of 33 to 34‰ predominate here. In the tropics, the largest number of species of this order occur at depths less than 500 m and the greatest quantity of specimens occur at depths less than 100 m. In the latter case, water temperatures of 25° to 28°C and salinities of 34.5 to 36‰ predominate. In the 100 to 500 m layer, where species are numerous and shells are scarce, the water temperature is below 25°C and drops to 10°C in places. In the southern subtropics, notal, and Antarctic regions, typical representatives of this order occur infrequently and as single species. But sometimes the latter are represented by many specimens as, for example, in the southern subtropics and notal regions at 1,000 to 1,500 m depths and in water temperatures of approximately 3° to 6°C, and in the notal region at 100 to 300 m depths and water temperature of 5° to 10°C and salinities of 34 to 35‰ (fig. 53).

From the above material it is clear that high water temperatures (above 15°C) and shallow depths characterize typical representatives of the order Textulariida. They also comprise many species and specimens. At lower water temperatures (10° to 15°C), there are still many species, but only single specimens are found. At water temperatures of 5° to 10°C, some individual species may form large shell deposits in some areas, while below 5°C the quantity of shells is 10 times less. All this is typical of depths less than 1,500 m in the tropical and notal regions. At great depths in the Pacific Ocean (below 3,000 m) species of the orders Pseudobolivina, Siphotextularia, and Spiroplectamina occur.[1] In this region here they are marked by large shell deposits in some areas. In the Antarctic, large numbers of specimens of these genera occur at lesser depths up to 300 m. In all these regions, the water temperature does not exceed 2°C.

143 The order Ataxophragmiida is represented by 31 genera and 141 species in the Pacific Ocean. In different regions of the ocean, this order is characterized by differing numbers of shells and species of foraminifera. In the boreal region, this order has the most species (30 to 50 species) and specimens (190 to 200 spcm) at depths of 50 to 400 m and below 2,250 m.

At intermediate depths, only half as many species and one-tenth as many specimens occur. Below 400 m depths, the water temperature changes, fron northwest to southeast, from 2° to 20°C, while below the 2,500 m depth, it is less than 2°C. In the northern subtropics, many species with few specimens occurred at depths less than 500 m, but many species and specimens occurred at depths less than 100 m and between 500 and 1,000 m. Deeper, the number of species drastically

[1]It seems that attachment of these genera to the order Textulariida needs clarification.

decreases, but, in places, they are represented by many specimens, as, for example, at 2,000 to 2,500 m depths (1.82° to 2.5°C water temperatures) and at 3,000 to 3,500 m (1.5° to 1.78°C water temperatures). In the southern subtropical and notal regions, this order occurs at all depths, with an insignificant number of species represented, in some places, by many specimens. These depths are at 100 to 300 m in notal region, and at the same depths and at 1,000 to 1,500 m and 2,500 to 4,500 m in the northern subtropics. In the Antarctic, the number of species is generally the same as in the boreal region, but is somewhat greater at depths of less than 1,000 m. These species are represented by a large number of specimens, especially at depths less than 2,000 m (fig. 54).

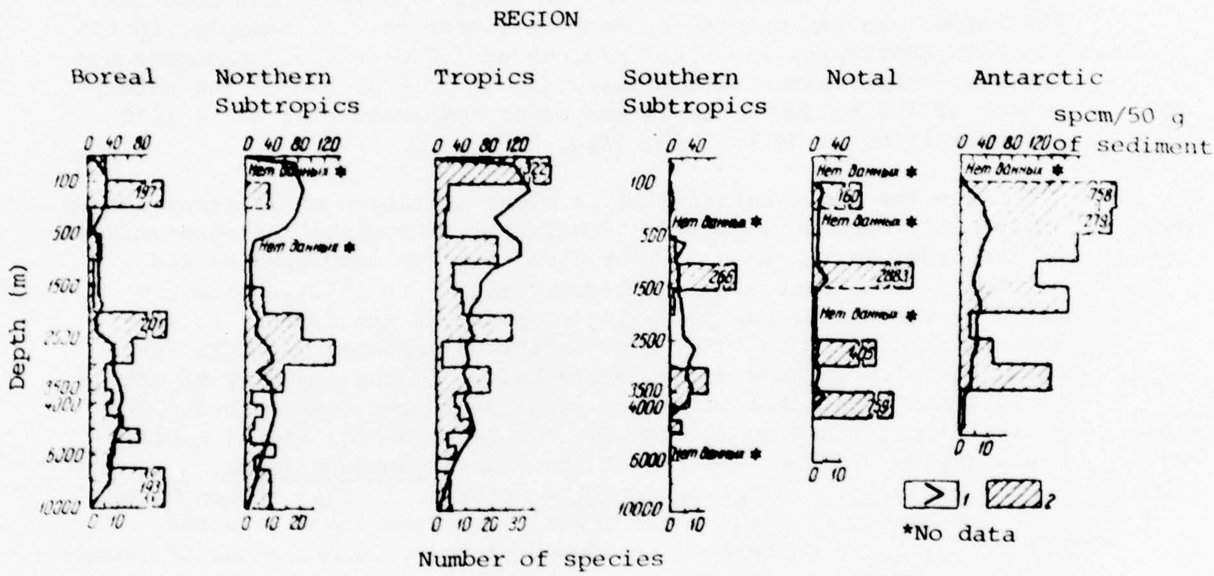


Fig. 54. Variation with depth of the number of species and specimens of the order Ataxophragmiida in different zoogeographic regions of the Pacific Ocean.

1. number of species; 2. arithmetic mean content of specimens in 50 g of sediment.

If one investigates the distribution of the genera of this order by depths and latitudes, one will discover that Verneuilina, Gaudryina, Clavulina, Clavulinoides, Textularia, Dorothia, Goesella, and Karreriella generally predominate in the northern subtropics and tropics at depths of less than 1,000 m. The largest number of species of these genera occur in water temperatures above 15°C. At water temperatures of 10° to 15°C, the species are even more numerous, but are represented by fewer specimens. At water temperatures of 3° to 10°C, only individual species are found which, in some places, are
144 represented by more specimens. Consequently, this group of genera are warmth-loving and shallow-water fauna of the order Ataxophragmiida.

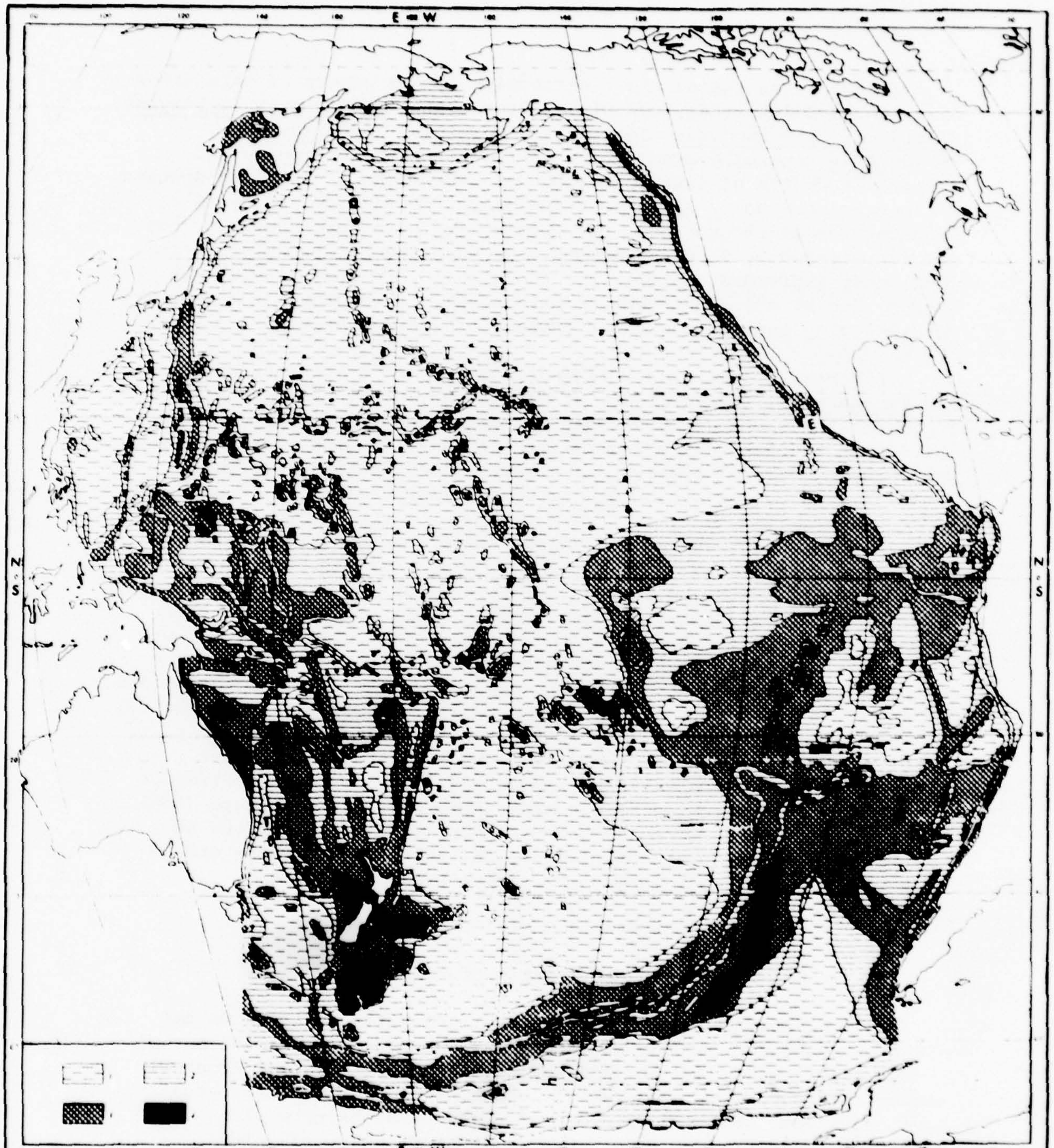
In boreal and Antarctic regions, species of the genera Trochammina and Trochamminella predominate at all depths. They also, generally represent the fauna of this order at depths greater than 2,000 to 3,000 m in the tropical and notal regions. All regions where there are large numbers of species and specimens of these genera are characterized by low water temperatures (below 2°C).

In conclusion, one should emphasize certain features of the vertical and horizontal distribution of orders of agglutinating foraminifera. In the boreal region, species of the order Ammodiscida predominate at all depths. These species comprise about 50% of all agglutinating species here. In the northern subtropics, species of the order Ataxophragmiida predominate (50 to 60%) at less than 1,000 m depths. At depths greater than 1,500 m, species of the orders Astrorhizida and Ammodiscida predominate (70 to 80%). In the tropics, at depths less than 750 m, 40% of the species belong to the order Ataxophragmiida and 30% to the Textulariida. At depths greater than 1,500 m, the same pattern is observed as in northern subtropics. In the Antarctic, species of the order Ammodiscida predominate (50%) at depths less than 200 m and greater than 1,000 m. At depths of 200 to 1,000 m, 30% of the species belong to the above order and 30 to 40% of the species belong to the order Ataxophragmiida.

SECRETIONARY BENTHIC FORAMINIFERA

Overall Quantitative Distribution

On the Pacific Ocean bottom, secretionary foraminifera do not exist everywhere, but only at depths less than 3,500 m in the boreal and Antarctic zones and at less than 4,500 m depths in the tropical and notal regions. In the Pacific Ocean, these foraminifera usually have calcareous shells composed more than 90% of calcite with differing admixtures of $MgCO_3$ (Brady, 1884; Walther, 1893-1894; Vinogradov, 1935; Blackmon, Todd, 1959) or, in extremely rare cases, of aragonite (Hagh, 1953; Troelsen, 1954; Todd, Blackmon, 1956). Secretionary foraminifera are distributed most widely south of 10°N. In the west, this region includes Melanesia, Macronesia, and New Zeland,



144a Fig. 55. Density of (calcareous) secretionary foraminifera in the Pacific Ocean (in spcm) 50 g of sediment)

1. not found; 2. 1-500; 3. 500-20,000; 4. >20,000

while in the east it includes the regions of the Albatross and East Pacific rises as well as adjacent slopes of the Northeast, Peru, and Chile basins. In the extreme south of the ocean, secretionary foraminifera are most widely distributed on the South Pacific Ridge (fig. 55). In these regions, their shells form more than 85% of all benthic foraminifera. Depths there do not exceed 4,500 m, while sediments are mainly organogenic planktonic foraminiferal oozes containing more than 30% $CaCO_3$. Only on the South Pacific Ridge are the sediments siliceous-calcareous (more than 30 to 50% amorphous $Si\ O_2$ and $CaCO_3$). From 10°N to 40°N, secretionary foraminifera are confined mainly to coastal regions and individual elevations where depths are less than 4,500 m. North of 40°N, these foraminifera do not descend below 3,500 m. In this region, the sediments are mainly terrigenous, non-calcareous (10% $CaCO_3$) and non-siliceous (10% SiO_2) or, as in the Okhotsk Sea, they are siliceous (30 to 50% amorphous SiO_2) diatom oozes.

In the Northwestern, Northeastern, South, Central, Peru, Philippine, Tasman, and Bellingshausen basins, secretionary foraminifera are almost absent. In these regions, depths are greater than 3,500 to 4,500 m, while sediments consist mainly of deep-water red clays (10% $CaCO_3$ and 5% amorphous SiO_2) or siliceous and terrigeneous oozes.

Comparing the chart of quantitative foraminiferal distribution in the Pacific Ocean with an ocean bottom relief chart, it is very clear that the areas of foraminiferal distribution and population density depend on bottom relief. The quantity of foraminiferal specimens on relatively negative relief features, at any level, is always smaller than on elevated positive relief features.

In the boreal region, secretionary foraminifera occur in greatest quantities at depths less than 200 m, at depths from 1,000 to 1,500 m (fig. 56).

In the northern subtropics, the quantity of these foraminifera is approximately 10 times that in the boreal region. The greatest quantities of specimens is usually observed at depths of 100 to 300 m, 1,000 to 1,500 m, and 2,500 to 3,000 m (5,000 to 10,000 spcm). There are data on the quantity of specimens at 0 to 100 and 300 to 1,000 m.

In the tropics, the highest mean density of secretionary foraminifera occurs at less than 300 m depths, where the quantity of these foraminifera reaches 38,000 to 70,000 specimens. This is 10 times more than in the northern subtropics and 100 times that in the boreal region. At 200 to 500 m depths, these foraminifera are fewer
146 (7,000 spcm). At greater depths the foraminiferal density decreases, and below 500 m the density does not exceed 1,500 to 2,000 spcm.

In the southern subtropics, the number of secretionary foraminifera is different at different depths. At depths less than 300 m, it generally averages 16,000 to 20,000 spcm; at 1,000 to 1,500 m - 34,000 spcm, at 2,500 to 3,500 m - 7,300 to 11,000 spcm. At the remaining intermediate depths, the number does not exceed 2,000 to 5,000 spcm. We have no data on the population density of foraminifera at 300 to 500 m depths.

In the notal zone, we have no quantitative data for 0 to 100 m, 300 to 500 m, and 1,500 to 2,500-m depths. At other depths, the number of specimens is large, but noticeably smaller than in southern subtropics. At depths of 100 to 300 m there were approximately 27,000 spcm, at 300 to 3,500 m - 11,000 to 18,000 spcm, and at 3,500 to 4,000 m - an average of about 30,000 spcm.

In the Antarctic, the number of foraminifera is considerably smaller than in the tropical and notal regions. The highest average density (1,500 to 3,000 spcm) occurred only at depths less than 500 m, at 1,500 to 2,000 m, and at 3,000 to 3,500 m. There are no data for depths less than 100 m. Comparison of the numbers of secretionary foraminifera shows that the fewest are in the boreal and Antarctic regions. This is due mainly to low water temperatures in these regions.

The relatively few secretionary foraminifera in the tropics at depths exceeding 500 m is related, it seems, to the shortage of nutrients, because the total plankton biomass is considerably smaller in this region than in nearby regions.

Bottom secretionary foraminifera with aragonite shells occur throughout the entire Pacific Ocean. To these foraminifera belong the Lobertinidae and Ceratobuliminidae. The comprise the largest numbers of specimens in tropical and notal regions at depths less than 500 m and near the Nanpo Shoto, Caroline, New Guinea, Tonga, Samoa, Tokelau, and Easter Islands and New Zealand. In these regions they even live below 3,000 to 4,000 m depths, but usually as individual specimens. In the boreal and Antarctic regions, foraminifera occurred as individual specimens, in regions of warm masses. All this indicates that foraminifera with aragonite shells are relatively warm-water and shallow-water (types).

Bottom secretionary foraminifera having shells of a single calcite crystal to which representatives of the family Spirilinidae belong, are found in all regions of the Pacific Ocean except the boreal (region). These foraminifera occur most widely in the same regions as foraminifera with aragonite shells, but usually as individual specimens. In the tropics, these foraminifera occurred at depths of 20 to 1,000 m, but most of them were at depths of 100 to 200 m in the Easter Island region. In the remaining regions, they do not descend below 500 m. Species whose shells consist of cryptocrystalline calcite

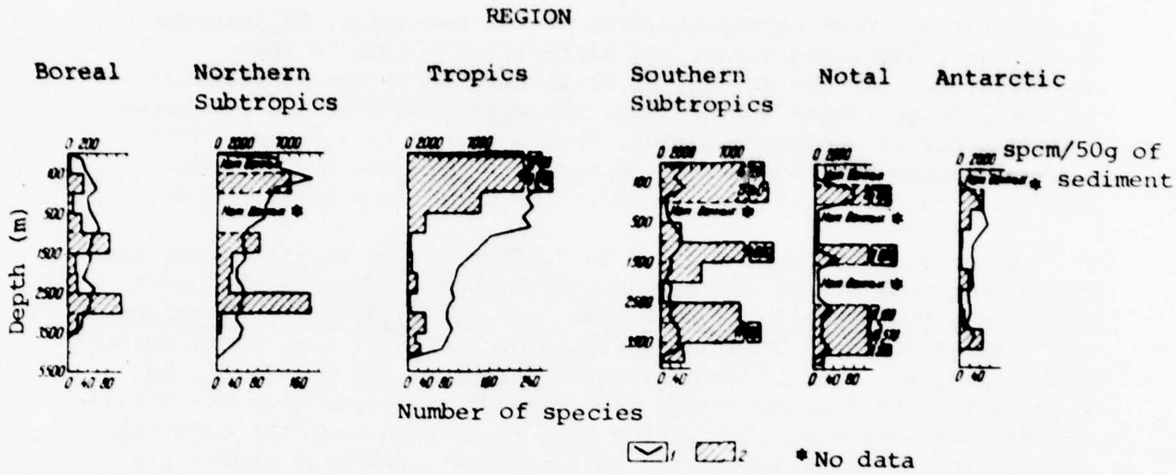


Fig. 56. Variation of secretionary benthic foraminiferal content with depths in different zoogeographic regions of the Pacific Ocean.

1. number of species; 2. geometric mean content of specimens in 50 g of sediment

of radial structure exist mainly at depths less than 2,000 m.

Secretionary foraminifera with wall structures of granular or microcrystalline calcite are most widespread at 2,000 to 2,500 m to 3,500 to 4,500-m depths in all regions of the Pacific Ocean. At lesser depths, they most frequently occur in the Antarctic. Species with glass or porcelain-like shells, belonging to the order Miliolida, comprise the greatest percentages relative to all other foraminifera in the northern subtropics at depths of 100 to 300-500 m and in the tropics at depths less than 200 m.

147 As mentioned above, secretionary bottom foraminifera make their shells mainly of $CaCO_3$ with different admixtures of Mg of 0 to 25 mole %, which replaces Ca in the shell structure (Blackman, Todd, 1959). The magnesium content in shells is determined by the water temperature and the systematic attributes of the foraminifera. Shells of foraminifera living at temperatures of 1° to 15°C, as a rule, contain no more than 10 mole % of Mg. At temperatures above 20°C, some foraminifera contain up to 24 mole % of Mg and, therefore, can be called high magnesium foraminifera. In the tropical regions these foraminifera are representatives of the Miliolidae, Calcarinidae, Planorbulinidae, Homotremidae, and certain species of Buliminidae (Buliminella, Buliminoides), Discorbidae (Discorbis), Rotalidae (Epistomaroides, Poroeponides, Stomatorbina). But most benthic foraminifera contain very little Mg (maximum 10 mole %) even at high

temperatures. Most representatives of the Lagenidae, Buliminidae, Rotaliidae, Amphisteginidae, and Elphidiidae belong to these foraminifera. If the Mg content of foraminiferal shells relative to their depth ranges are studied, one will find that low-magnesium shells occur at different depths, from almost 0 to 3,500 m, while high-magnesium shells occur at depths less than 200 m. No high-magnesium foraminifera were found in the boreal and polar regions.

At great depths, from 3,800 to 7,225 m in the Pacific Ocean are found specimens of two secretionary species belonging to the order Miliolida, *Miliolinella legis* Saidova and *Involvohauerina globularis* Loeblich et Tappan. Chemical analysis of shells of the latter species shows that they contain twice as much strontium and magnesium, but only half as much aluminum and five times less copper than the shells of shallow-water miliolids. From this it is seen that the chemical composition of abyssal forms is quite diverse, and they apparently cannot be classified as typical calcareous foraminifera. The shells of large miliolids found by Brady at depths of 7,230 m are covered by a thin homogeneous layer of silica (Brady, 1884).

DISTRIBUTION OF SECRETIONARY FORAMINIFERAL SPECIES

The fauna of bottom secretionary foraminifera is quite numerous. It now consists of approximately 1,300 species belonging to 6 orders, 32 families, and 300 genera. The relationship of these foraminifera to depth is quite varied (fig. 57). Stenobathic species live mainly at depths less than 2,000 m and specifically, at depths less than 500 m. The depth zone within which they live on the continental shelf lies within the limits of 50 to 100 m. The habitat ranges for species that live at depths of 500 to 750 to 2,000 m increases to 250 to 500 m, and relatively stenobathic species appear here. At depths greater than 2,000 m to 3,500 to 4,500 m, relatively eurybathic species with habitat ranges of 50 or 100 m predominate. But some species at these depths have the same habitat ranges as shallow-water species. In comparison to agglutinating foraminifera, secretionary species are, on the whole, more stenobathic. In the entire Pacific Ocean, 18 vertical groups of secretionary foraminifera can generally be identified. Each group contains a large percentage of endemic forms.

In the Pacific Ocean, the number of species decreases sharply with depth. The greatest number of these species are at depths of 50 to 300 - 440 m. Below, the total become fewer and fewer. Sharp jumps in the number of species are noted at 50, 500, and 2,000 m levels; from 500 to 2,000 m, the number of species decreases very sharply, while in greater depths from 2,000 to 4,500 m, (they decrease) slowly (fig. 58).

149 The number of species of bottom secretionary foraminifera in different latitude zones of the Pacific Ocean varies sharply; there are about 190 species in the boreal zone, 460 in the northern subtropics,

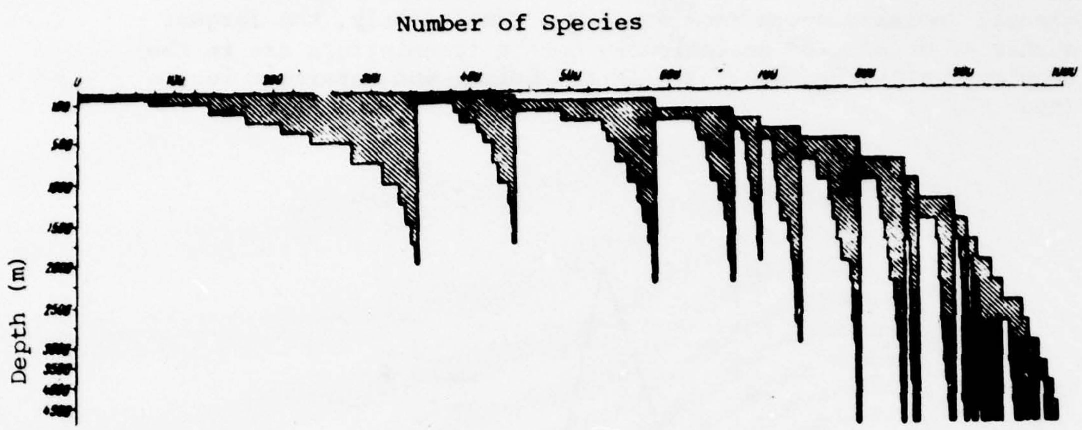


Fig. 57. Quantitative distribution of species of benthic secretionary foraminifera in the Pacific Ocean by depths.

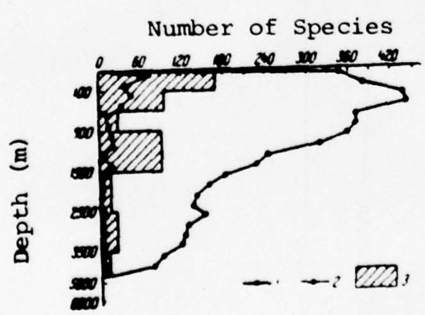


Fig. 58. Quantity of endemic species of benthic secretionary foraminifera at various depths in the Pacific Ocean.

1. total number of species; 2. number of endemic species each for 50, 100, 250, and 500 m; 3. number of endemic species.

825 in the tropics, 325 in southern subtropics, 235 in the notal region, and 110 in the Antarctic. A gradual increase in numbers of species from the north to the equator is observed, as well as a gradual decrease south from the equator. Consequently, the largest number of species of secretionary bottom foraminifera are in the tropics, while the fewest are in the boreal and Antarctic region (fig. 59).

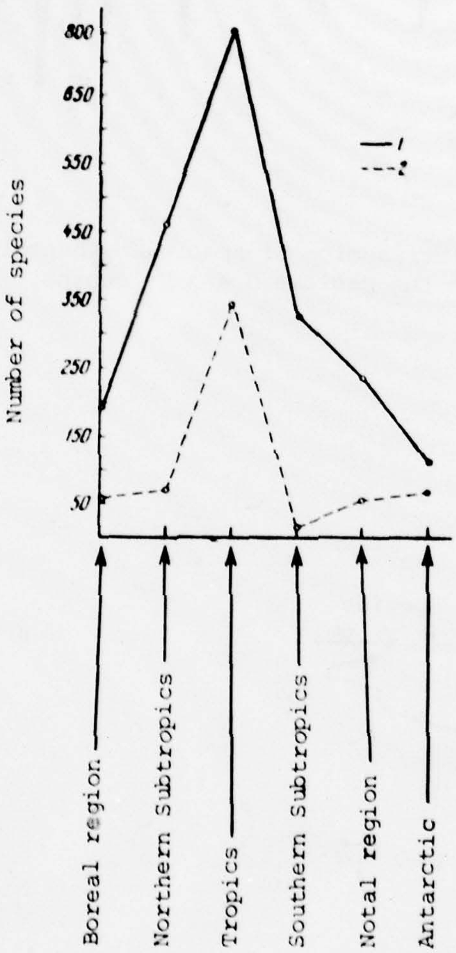


Fig. 59. Variation of the number of all species and of endemic benthic secretionary foraminifera in the Pacific Ocean depending on latitude.

1. total number of species; 2. number of endemic species.

The latitude distribution of species of secretionary bottom foraminifera is quite diverse. In the boreal region, the number of species at different depths is similar and varies from 25 to 60. But even in this region, one can distinguish depths containing more of them: 200 to 300 m, 750 to 1,000 m, and 2,250 to 2,500 m. The higher maximum number of species coincides with the maximum quantity of specimens of these foraminifera. The maxima for two deeper species is a little higher than the quantitative maxima. The greatest number of these foraminifera occurs at 2,500 to 3,000-m depths. In this region, the secretionary species do not go below 3,500-m depths (fig. 56).

In the northern subtropics, the number of species changes considerably in the vertical direction. At depths less than 300 m, are 100 to 500 of them, and they are represented by many specimens. At 300 to 1,000-m depths, the number of species dwindles gradually. At depths greater than 1,000 m, there are half as many species as at shallower depths. At 2,500 to 3,000-m depths the largest number of specimens occur. Water temperatures at depths less than 300 m are approximately 10° to 17°C and the salinity is 34.5 to 35.0‰. At depths greater than 1,000 m, water temperatures are 1.5° to 4°C and the salinity is 34.25 to 34.7‰ (Muromtsev, 1958, 1963; Stepanov, 1962).

In the tropics, one can distinguish some regions in the 0 to 1,000-m layer, that contain the largest number of species (up to 250), (water temperature above 5°C and salinity 34.4 to 35.5‰. However, these species are characterized by the greatest quantities of specimens at depths of less than 500 m, in water temperatures above 9°C, and a salinity of 34.6‰. Below 1,000 m, the number of species decreases gradually to 2,000-m depths, below which it is 2.5 times smaller than at 0 to 1,000-m depths and they are represented by 20 times fewer specimens. The water temperature here is below 2.5°C and salinity is above 34.63‰.

In the southern subtropics, the number of species varies insignificantly with depth (from 10 to 45). The greatest numbers (of species) are found at depths of 0 to 300 m, 750 to 1,250 m, and 3,000 to 3,750 m. The most numerous specimens of these species occur at approximately the same depths.

150 In the notal region, few species were found at all depths. The greatest number of species occurred at depths of at 100 to 300 m, 1,250 to 1,500 m, 2,500 to 2,750 m, and 3,500 to 3,750 m. The same depths were those characterized by large quantities of specimens.

In the Antarctic, the greatest number of species occurred at 700 to 750-m depths. Deeper, the number was reduced to half. The greatest density of foraminiferal occurred here at depths of 100 to 500 m and 3,000 to 3,500 m.

From the above data, it is seen that the largest numbers of species and specimens of secretionary bottom foraminifera occur at 0 to 1,000-m depths in the tropics and at 0 to 300-m depths in the northern subtropics. These species constitute shallow-water, warmth-loving fauna of the secretionary bottom foraminifera of the Pacific Ocean. Elements of this fauna also occur in the southern subtropics and notal region at depths less than 200 to 300 m. These foraminifera are represented here by a few species with a large number of specimens.

The cold-water shallow-water, secretionary foraminiferal fauna in the boreal and Antarctic regions, at 0 to 500-m depths consist of a few species having the largest numbers of specimens in the Antarctic region.

At the present time, as mentioned above, about 1,300 species of secretionary bottom foraminifera were identified in the Pacific Ocean. Below we will discuss mainly the distribution of the stenobiontic species endemic to various regions of the Pacific Ocean. The presence of a large number of endemic species at depths less than 100 m is characteristic of the Pacific Ocean as a whole (fig. 58).

They decrease below at 100 to 1,500 m, and at depths greater than 1,750 m, the number of endemic species is no more than 10 or 12. If the total of all endemic species in the vertical zones is examined, one will find that most of them are in the sublittoral zone and the upper subzone of the bathyal zone.

Most latitudinally endemic species of secretionary foraminifera are in the tropics, where there are 350 of these species, while the fewest (12 species) are in the southern subtropics. Farther south, the number increases to 55 in the notal region and to 65 in the Antarctic. The boreal region is similar to the notal region (fig. 59). Among all species endemic to the boreal region, 40.7% live at depths less than 300 to 500 m, 27% at 300 to 500-to-2,000-m depths, and 27% at depths greater than 2,000 m. In the northern subtropics, 68% of all the species endemic to this region were found at depths less than 300 to 500 m, 12% at 300 to 500-to-2,000-m depths, and 5% at depths greater than 2,000 m. In the tropics, 53% of all the species endemic to this region occurred at depths less than 300 to 500 m, 27% at 300 to 500- to 2,000-m depths, and 8.7% at depths greater than 2,000 m; in the southern subtropics, 86.7% were at depths less than 300 to 500 m and 13.3% at depths of 300 to 500-to-2,000 m; in the notal region, 74.5% were at depths less than 300 to 500 m and 25.5% at depths of 300 to 500-to-2,000 m; in the Antarctic region, 41% were at depths less than 300 to 500 m, 17% at depths of 300 to 500-to-2,000 m, and 11.8% at depths greater than 2,000 m (fig. 60). The remaining
151 secretionary bottom foraminifera extend from one latitude zone into another.

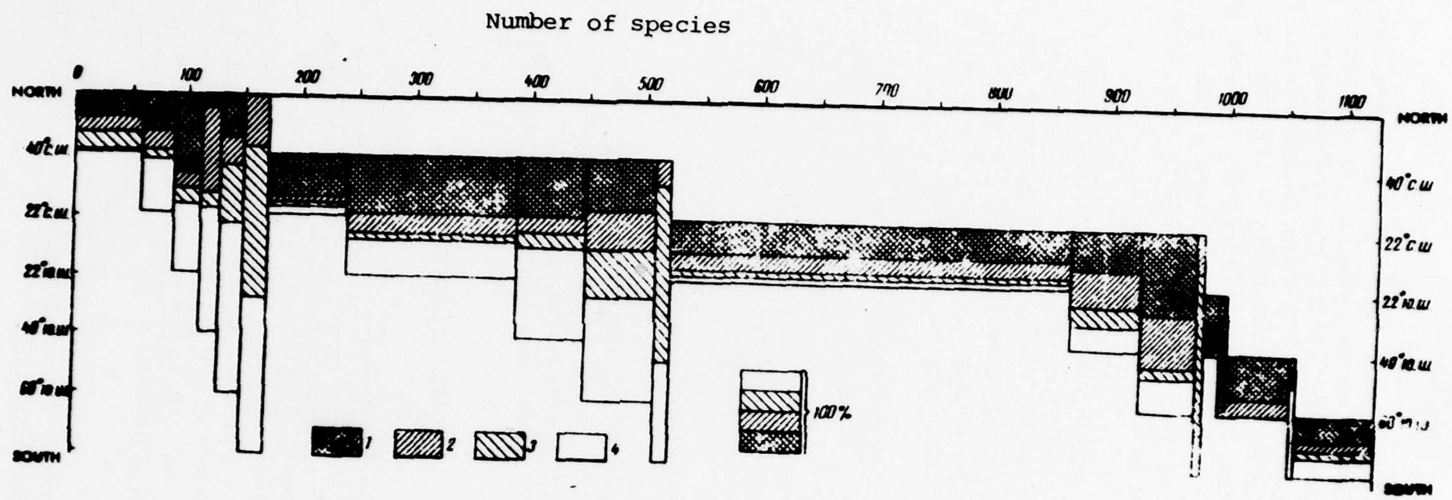


Fig. 60. Distribution of species of secretionary bottom foraminifera by latitudes and percentage of the deep-water and shallow-water species in each latitude region.

1. percentage content of species living at 0 to 300-500 m depths; 2. at 300-500 to 2,000 m; 3. below 2,000 m; 4. transitional species.

Most transitional species occur between the northern subtropics and the tropics, while the fewest occur between the southern subtropics and the notal region and between the latter and the Antarctic region. Based on agglutinating and secretionary bottom foraminiferal fauna, the Pacific Ocean can be divided into two parts - the northern, lying north of 22°S and the southern, lying south of 22°S. The northern part is very rich in secretionary foraminiferal species. Here, in the boreal and northern subtropics regions, 511 species were found, while only 454 species occurred in the southern part.

Principally deep-water secretionary foraminifera that live at depths greater than 1,500 to 2,000 m, or eurybathic species that move from one region to another live in the northern part of the ocean. In the southern part of the ocean, these and many shallow-water species move from one latitude region to another, especially from the southern subtropics to the notal region.

All species of secretionary bottom foraminifera can be divided into three groups. The first group consists of latitudinally and bathymetrically stenobiontic species. The second group consists of
152 stenobathic species that are latitudinally eurybiontic. The third group consists of latitudinally stenobiontic species that are relatively eurybathic.

STENOBIONTIC SPECIES

715 species can be assigned to the first group. Most of them are typical of the sublittoral zone and upper part of the tropical bathyal zone. Below we will present species endemic to the main latitudinal regions of the Pacific and confined to specific vertical zones.

BOREAL REGION

Sublittoral Zone: *Quinqueloculina borealis* Saidova, *Q. subarctica* Saidova, *Q. arctica* Cushman, *Triloculina ochotica* Saidova, *Sigmoilina borealis* Saidova, *Cruciloculina asanoi* Loeblich et Tappan, *Dentalina linearis* Williamson, *D. frobisherensis* Loeblich et Tappan, *Vaginulina alecsandra* Saidova, *Pseudopolymorphina charlottensis* Cushman, *Guttulina cumulata* Saidova, *Polymorphina kincaida* Cushman et Todd, *Discorbis borealis* Saidova, *Buccella frigida* Cushman, *B. inusitata* Loeblich et Tappan, *Cibicides greiames* Saidova, *Discorbis* sp. 5, *Elphidium subclavatum* Gudina, *Cribroelphidium goesi* Stschedrina, *Elphidiella arctica* Parker et Jones, *E. argutum* Saidova, *Planoelphidium oregonense* (Cushman et Grant), *Protoelphidium orbiculare* (Brady), *Cassidulina smechovi* Voloshinova, *Ehrenbergina* sp. 1, *Uvigerina peregrina* Cushman subsp. *magnocostata* Saidova.

Bathyal Zone:

Upper Subzone: Purgo murrhyna murrhyna (Schwager) subsp. surtida Saidova, P. derjugini Saidova, Lenticulina crepidula Fichter et Moll, Planularia sp. 1, Pullenia noncarinata Saidova, Nonionella modesta Saidova, Nonionellina subscapha Saidova, Cribroelphidium sp. 1, Bulimina inflata Saidova, Uvigerina echinata Saidova, U. ochotica Saidova, Cassidulina ochotica Saidova, Cassidulinoides ochoticus Saidova, Ehrenbergina ovalis Saidova, Chilostomellina fimbriata Cushman.

Lower Subzone: Quingeloculina recenta Saidova, Q. sorolica Saidova, Q. sp. 4, Triloculina praealta Saidova, Purgo murrhyna alta Saidova, Lenticulina sp. Valvulineria ochotica Stschedrina, Oridorsalis umbonatus subsp. umbonatus (Reuss), Eponides profundus Saidova, Heglundinae legans (Orbigny) subsp. alta Saidova, Pullenia subcarinata Orbigny subsp. praealta Saidova, Elphidium batialis Saidova, Ehrenbergina trigona (Goes).

TROPICAL REGION

Tropical Zone:

Northern Subtropics: Quinqueloculina neostriatula Cushman et Todd, Q. akneriana Orbigny, Q. laevigata Orbigny, Q. subquadra Hada, Q. pugmaea Reuss, Q. seminulum (Linnaeus), Q. rotundata (Orbigny), Q. rhodiensis Parker, Q. elongata Natland, Q. gigas Natland, Q. catalinensis Natland, Q. granulosa Natland, Spiroloculina hadai Thalman, Triloculina terquemiana (Brady), Pseudolingulina comis Saidova, Planularia subarcuatula (Montagu), Marginulina triremisa Saidova, Dentalina communis Orbigny, D. mutsui Hada, Guttulina gibba (Orbigny), Pseudopolymorphina soldanii (Orbigny), Sigmomorphina ozawai Hada, Discorbis monicana Zalesny, Valvalineria vilardeboana (Orbigny) var. glabra? Cushman, Baggina columbiensis (Cushman), Eponides ornata (Orbigny), Robertina californica? Cushman et Parker, Anomalina sp. 2, Hanzawaia panamensis (Natland), Nonion depressulum (Walker et Jacob), Astrononion gallowayi Loeblich et Tappan, A. stellatum Cushman et Edwards, Nonionella monicana Zalesny, Rotalia lomaensis Bandy, Elphidium advenum Cushman subsp. miyatense Fujita, E. kusiroense Asano, E. subgramulosum Asano, Cribroelphidium etigoensis Husezima et Maruhasi, Nonionellina japonica (Asano), Virgulina californiensis Cushman, Bulimina aculeata? Orbigny, B. pagoda Cushman var, hebespinata Stewart, Chrysalidinella dimporpha (Brady), Rectouvigerina schencki (Asano), Siphoegerina semistriata (Schubert), Cassidulina limbata (Sushman et Hughes), C. sp. 2, Bolivina quadrata Cushman et McCulloch, B. goudkoffi Rankin, B. tosaensis Asano, Spirillina operculoides Cushman.

Bathyal Zone:

Upper Subzone: Guttulina yamozakii Cushman et Ozawa, Valvulineria inaequalis (Orbigny), V. araucana (Orbigny), Gyroidina gemma Bandy, Nonionellina scapha (Fichtel et Moll), Uvigerina striatula Cushman, Bolivina variabilis (Williamson).

Lower Subzone: Hanzawaia nitidula (Bandy), Bulimina spinosa (Heron-Allen et Earland), Bolivina vaughani Natland.

Depths Greater Than 3,500 m: Favocassidulina elegantissima (Orbigny).

Northern Subtropics - Tropics:

Sublittoral Zone: Cornuspira foliacea (Philippi), Quinqueloculina lamarkina Orbigny, Q. inaequalis Cushman, Q. poeyana Orbigny, Q. fichteliana (Orbigny), Miliolinella sublineata (Brady), Spiroloculina clara Cushman, S. orbis Cushman, Hawerina compressa Orbigny, H. circinata Brady, Nodobaculariella striata (Orbigny), Triloculina bassensis Parr, Pyrgo denticulata (Brady), P. striolata (Brady), Nodosaria catenulata Brady, Pseudolingulina gratia Saidova, Frondicularia robusta Brady, Robulus reniformis (Orbigny), Vaginulina surtida Saidova, Polymorphinella pacifica (Cushman et Hanzawa), Pseudopolymorphina jugosa (Cushman et Ozawa), Dimorphyna tuberosa (Orbigny), Sigmoidella kagaensis Cushman et Ozawa, Pseudoglandulina rotundata (Reuss), Discorbis isabelleana? (Orbigny), Cancris subauriculum Saidova, Eponides margaritifera (Brady), E. manusus Saidova, Lamarckina ventricosus (Brady), Robertina charlottensi (Cushman), Amphistegina lessoni Orbigny subsp. surtida Saidova, Anomalina glabrata Cushman, Cibicidina foliora Saidova, Cibicides rarescens (Brady), Nonionella basiloba Cushman et McCulloch, Florilus baueana (Orbigny), F. decorata (Cushman et McCulloch), F. japonicum (Asano), F. pizarrense (Berry) var. basipinatum Cushman et Mover, Carterina balaniformis Gray, Elphidium macellum (Fichtel et Moll), E. spinatum Cushman et Valentine, E. frigidum Cushman, Parrellina pustulosum (Cushman et McCulloch) Baculogypsinoides spengleri (Gmelin), Cribroeponides clivosus Saidova, Cycloclypeus quembelianus Brady, Buliminella elegantissima (Orbigny) var. limbata (Terquem), B. curta Cushman, B. parallela Cushman et Parker, Sigmovirgulina tortuosa (Brady), Hopkisina karreriana (Brady) var. carinata (Cushman), Laxostomum instabile Cushman et McCulloch, Bifarina mackinnoni (Millett), B. fimbriata (Millett), B. hancocki Cushman et McCulloch, Siphogenerina pacifica (Cushman et McCulloch), Bulimina denudata Cushman et Parker, Uvigerina proboscidea Schwager, U. schwageri Brady, U. excellens Todd, Milletia tessellata (Brady), Angulogerina fluens Todd, A. agrestus Todd, A. baggi (Galloway et Wissler), Bolivina minuta Natland, B. acerosa Cushman var. pacifica Cushman et McCulloch, B. laevigata (Williamson), B. capitata Cushman, B. advena Cushman var.

striatella Cushman, B. tongi Cushman var. filacostata Cushman et McCulloch, B. costata Orbigny, B. striatula Cushman, B. subadvena Cushman var serrata Natland, B. pseudoplicata Heron-Allen et Earland, B. torqueata Cushman et McCulloch, Bolivinoides albatrossi (Cushman), Spirillina limbata Brady, S. decorata Brady.

Bathyal Zone:

Upper Subzone: Quinqueloculina lamarkina? Orbigny, Q. pygmaea Reuss, Q. ceres Todd, Ptychomiliola costifera (Cushman), Valvulineria inflata (Orbigny), V. glabea (Cushman), Pseudoparella smithi (Stewart), Planorbulina acervalis Brady, Streblus lepidus Cushman, Virgulina
154 cornuta Cushman, V. seminuda Natland, Hopkisina karreriana (Brady) var. carinata? (Cushman), Bulimina pagoda Cushman, B. subornata Brady, Pavonina flabelliformis Orbigny, Unicosiphonia tropica (Asano), Cassidulina angulosa subsp. angulosa Cushman, Ehrenbergina albatrossi Cushman, Cassidulina marshallana Todd, C. elegans subsp. elegans Todd, C. caudriae Cushman et Stainforth, Brizalina robusta (Brady), Attomorphina trigona Brady, Spirillina tuberculata Brady.

Lower Subzone: Pyrgo erratula (Cushman), Pullenia subsphaeroides Saidova, Astrononion infirmis Saidova, Bolivina cancellata Saidova, Sipho ivigerina spinescens Saidova.

Depths Greater Than 3,500 m: Globulina lactea (Walker et Jacob), Cassidulina elegans Todd subsp. enodata Saidova.

Northern Subtropics - Southern Subtropics:

Sublittoral: Cornuspira ex. gr. involvens Reuss, Quinqueloculina parkeri (Brady, Q. ex. gr. linaeana (Orbigny), Triloculina tricarinata Orbigny, Peneroplis planatus (Fichtel et Moll), Sorites marginalis (Lamarck), Robulus sp. 16, Sigmoidella pacifica Cushman et Ozawa, Siphonina echinata (Brady), Poroeponides cribrorepandus Asano et Uchio, Amphistegina pulchra Cushman et Todd subsp. surtida Saidova, Cibicides lobatulus? (Walcker et Jacob), Nonionella turgida (Williamson), Gypsina vesicularis Parker et Jones, Planorbulinella larvata (Parker et Jones, Cribroelphidium articulatum (Orbigny) var. rugulosum (Cushman et Wickenden), Loxostomum bramlettli (Kleinpell), L. mayori (Cushman), Bolivina doniezi Cushman et Wickenden, B. subexacavata Cushman et Wickenden, Bolivinella folia (Parker et Jones), Spirilina inaequalis Brady.

Bathyal:

Upper Subzone: Robutus cultrata (Montfort), Cibicidina fumeus Saidova, Heminwayina turbo (Orbigny), Rectobolivina bifrons (Brady) var. striatula Cushman, Cassidulina calabra Seguenza, C. crassa crassa Orbigny.

Lower Subzone: Spiroloculina alta Saidova, Francesita advena (Cushman), Virgulina texturata Brady, Bulimina buchiana Orbigny, Uvigerina ampulacea subsp. ampulacea Brady, Angulogerina bradyana Cushman, Cassidulina cushmani Stewart et Stewart.

Depths Greater Than 3,500 m: Cassidulina spiralis Natland subsp. profundissima Saidova.

Tropics:

Sublittoral Zone: Cornuspira carinata (Costa), C. lacunosa
Brady, Nubecularia lacunensis Chapman, N. tubulosa Heron-Allen et
Earland, Planispirina exigua Brady, Ophthalmidium tumidulum Brady,
Spirophthalmidium parvula (Chapman), S. acutimargo (Brady),
Quinqueloculina albatrossi Cushman, Q. amygdaloides (Brady), Q.
anguina Terquem, Q. bosciana (Orbigny), Q. berthelotiana? Orbigny,
Q. bicarinata (Orbigny), Q. bradyana Cushman, Q. costata Orbigny,
Q. crassa Orbigny var. subcuneata Cushman, Q. circularis (Borneman)
var. sublineata (Brady), Q. cuneata (Karrer), Q. curtaCushman, Q.
cuvieriana (Orbigny), Q. disparilis Orbigny var. curta Cushman,
Q. gualtieriana Orbigny, Q. gracilis Orbigny, Q. humilis Cushman et
Ellisor, Q. ferussacii (Orbigny), Q. kerimbatica (Heron-Allen et
Earland), Q. laysanensis (Rhumbler), Q. neostriatula Thalman, Q.
undosa (Karrer), Q. planata (Cushman), Q. repertiana (Brady), Q.
rugosa Orbigny, Q. suborbicularis (Orbigny). Q. striatula Cushman,
Q. striata Orbigny, Q. sculpturara Cushman, Q. samaraica Saidova,
Q. tropicalis Cushman, Q. venusta (Karrer), Triloculina marshallana
Todd, Massilina cultrata (Brady), M. convexiuscula? Brady, M. durrandii?
Millett, M. macilenta (Brady), M. milletti (Cushman), M. Pacificensis
Cushman, M. repertiana? (Brady), Miliolinella bradyi (Millett), M.
oblongo (Montagu), M. valvularis (Reuss), Miliola circularis (Borneman)
var. sublineata (Brady), Articulina lineata Brady, A. milletti (Cushman),
A. pacifica (Cushman), A. scrobiculata (Brady), Tubinella funalis (Brady),
155 T. chapmani Cushman, T. funalis var. inornata (Brady), Nubeculina
divaricata (Brady), Spiroloculina planissima (Lamarck), var. samoaensis
Cushman, S. nitida Orbigny var. foveolata Egger, S. planulata (Lamarck),
S. manifesta Cushman et Todd, S. mayori Cushman, S. limbata Orbigny,
S. grateloupi Orbigny var. serrulata Cushman, S. grateloupi Orbigny var.
acescatea Cushman, S. planissima (Lamarck), S. communis? Cushman et Todd,
Flintina triquetra (Brady), F. bradyana Cushman, Hauerina ornatissima
Brady, H. pacifica Cushman, Nodobaculariella insignis (Brady), Pyrgo
bicermula (Schwager), Idalina coronata (Millett), Vertebralina striata
Orbigny, Peneroplis proteus Orbigny, P. politus? Chapman, P. sollasi
Chapman, P. solitus Chapman, Monolisidium lituus (Gmelen), Orbitolites
compresso (Orbigny), Alveolinella boscii (Defrance), Nodosaria catenulata?
Brady, N. subtertenuata Schwager, N. sublineata (Brady), Siphonodosaria
perversa (Schwager), Lingulina carinata Orbigny, Frondicularia anularis
Orbigny, F. interrupta Karrer, F. spathulata Brady, F. tenera (Bornemann)

Astacolus crepidula (Fichtel et Moll), A. sp. 5, Planularia cassis (Fichtel et Moll), P. spinipes (Cushman), P. dorso-costata (Cushman) P. gibba (Orbigny), P. gemmata (Brady), P. siddaliana (Brady), P. Mirabilis (Chapman), P. sp. 5, Robulus cultrata? (Mintfort), R. nitida (Orbigny), R. clericii (Fornasin), Marginulina philippinensis Cushman, Marginulina musai Saidova, M. sublineata (Cushman), Saracenaria angularis Natland, S. jamaicensis (Cushman et Todd), Guttulina quinquecostata Cushman et Ozawa, Guttulina sp. 1, Pseudopolimorphina indica (Cushman), Sigmoidella segnenzeana (Brady), Sigmomorphina semitecta (Reuss) var. terquemiana (Fornasini), Discorbis opima Cushman, D. ilaensis Saidova, D. frustata Cushman, Semirosalina tuberocapitata (Cushman), Glabraltella piramidalis (Heron-Allen et Earland), Baggina philippinensis (Cushman), Cancris peroblonga (Cushman), Eponides praecincta (Karrer), E. meridionalis Cushman et Kellett, Siphonina tubulosa Cushman, Epistominella pulchra (Cushman), Epistomoroides polystomelloides (Parker et Jones) Cushmanella primitiva Cushman et McCulloch, Pseudobulimina convoluta (Williamson), Cibicides ungerianus (Orbigny), C. panamensis (Natland), C. pacifica (Cushman), C. mayori (Cushman), Nonionella subturgida (Cushman), Florilus incisum (Cushman), F. hancocki (Cushman et McCulloch), Astrononion alaterus Saidova, Carpenteria monticularis Carter, Cymbaloporella tabellaiformis (Brady), Tretomphalus millettii (Heron-Allen et Earland), Streblus fijiana Cushman, Elphidium oceanicum Cushman, E. reticulosum Cushman, Elphidiella sp. 1, Parellina verriculata (Brady), P. stimulum (Cushman et McCulloch), Heminwayina vesicularis (Lamarck), Nummulites cumigii (Carpenter), Buliminella madagascariensis (Orbigny) var. spicata Cushman et Parker, Virgulina fijiensis Cushman, Grammostomum subangularis Cushman, Sagrina vertebralis (Cushman), Siphouvigerina convallarium? (Millett), Pavonina rynkyensis Cushman et Hanzawa, Rectobolivina limbata (Brady), Bulimina orientalis (Cushman), Globobulimina fijiensis Cushman, Chrysalidinella dimorpha (Brady), Trimosina perforata Cushman, T. simplex Cushman, Siphouvigerina porrecta Brady var. fimbriata Cushman, Uvigerina tennuistriata Reuss, Unicosiphonia virgula (Brady), Schubertia annulata (Brady), S. limbata (Brady), Pleurostomella rapha Gumbler, P. brevis Schwater, Orthoplecta clavata Brady, Cassidulina translucens Cushman et Hughes, C. sp. 5, Bolivina vadescens Cushman, B. subangularis Brady, B. simpsonii (Heron-Allen et Earland), B. semialata Bagg, Brisalina tenuis (Brady), Sagrina pacifica (Asano), Berthelinella subtenuis Cushman, Nodogenerina millettii Cushman, Spirillina spinigera Chapman, S. obconica Brady, S. henseni Rumbler, Conispirillina trochoidea Cushman, C. coronata Cushman, C. semiinvoiuta Cushman.

Bathyal Zone:

Upper Subzone: Cornuspira, Planispirina contraria (Orbigny),
156 Quinqueloculina berthelotiana Orbigny, Q. sorolica Saidova, Q. shuazewljca Saidova, Q. bukaensis Saidova, Q. polygona Orbigny, Q. apicula Cushman, Q. disparilis Orbigny, Meliolinella procera (Goes), Articulina tibia

(Jones et Parker), Spiroloculina grata Terquem var. angulata Cushman, S. regularis Cushman et Todd, S. costifera Cushman, Sigmoilina sp. 4. sigmoidea (Brady), Hauerina bradyi Cushman Troloculina austriaca Orbigny, T. feniks Saidova, Triloculina tongatobu Saidova, T. ataensis Saidova, S. sp. 11, Pyrgo depressa (Orbigny), P. irregularis (Orbigny), P. vespertilio (Schlumberger), P. comalta (Brady), P. tofuana Saidova, P. lucernula (Schwager), Sorites marginalis? (Lamarck), Nodosaria subtertenuata Schwager, N. pauviloculata Cushman, N. pyrula Orbigny, N. prava Cushman, N. substriatula Cushman, N. subpervessa Cushman, N. hispida Orbigny, N. solita (Reuss), Siphonodosaria protumida (Schwager), S. spinata (Cushman), Pseudolingulina sectio Saidova, Frondicularia philippinensis Cushman, Astacolus costata (Orbigny), A. peregrina (Schwager), Planularia compressa (Orbigny), P. cassinoides (Cushman), Robulus nigriseptus (Koch), R. costata (Fichtell et Moll), R. expansa (Cushman), R. helicina (Cushman), R. orbicularis (Orbigny), Robulus sp. 1, R. costatulus (Fichtel et Moll), Marginulina striatula Cushman, M. lequata Saidova, Saracenaria sp 1, S. versari Saidova, Dentalina japonica (Cushman), D. pomuligera Stache, Guttulina sp., Pyrulinoides aerugata Saidova, Sigmoidella virgulata Saidova, Discorbis sp., Valvulineria modica Saidova, Baggina subobtusa (Cushman), Eponides sp. 1, E. markus Saidova, Lamarckina soulcii (Orbigny), Amphistegina lessoni Orbigny subsp. alta Saidova, A. pulchra Cushman et Todd subsp. alta Saidova, Anomalinoides larvatus Saidova, Cibicides akneriana? (Orbigny), C. umbonatus Phleger et Parker, Hanzawaia bertheloti (Orbigny), Planorbulina mideterranensis (Orbigny), Rotalia calcar (Orbigny), Virgulina squamosa Orbigny var. striata Bagg, Siphogenerina terra Saidova, Rectobolivina bifrons (Brady), Globobulimina pyrula (Orbigny) var. spinescens (Brady), Elipsoidina ellepsoides Mattei, Rectouvigerina irregularis (Bagg), Cassidulina corbyi Cushman et Hughes, C. auri Saidova, C. spinifera Cushman et Jarvis, Cassidulina costatula Cushman subsp. pulchra Saidova, C. rosae Saidova, C. spiralis subsp. spiralis Natland, Bolivinita sculpturata (Cushman), Chilostomella grandis Cushman.

Lower Subzone: Quinqueloculina alta Saidova, Q. gaferut Saidova, Massilina australis Cushman, Miliolinella labiosa (Orbigny), Triloculina praealta Saidova, Pyrgo elongata (Orbigny), Saracenaria smaragdina Saidova, Dentalina sp. 2, Glandulina glans Orbigny, Pseudoglandulina aequalis (Karrer), Siphonina sp. 1, Asterigerina pacifica Saidova, Pullenia sp. 3, Osangularia subdentata Saidova, Globobulimina torta Cushman, Siphogenerina striatula Cushman, S. sp. 1, Bolivina ligularia (Schwager), Cassidulina sp. 1, C. delicata Cushman subsp. crustosa Saidova, C. subauri Saidova, C. gemma Todd, C. sp. 3, C. sp. 4, C. virgata Saidova, C. subspinifera Saidova, Ehrenbergina reticulata Cushman, Sugrunda globulosa (Cushman), Quadrimorphina laevigata (Phleger et Parker).

From 3,500 to 4,500 m: Siphoglobulina tibia Saidova, Florilus sp. 2, Ellipsoglandulina occidentalis Saidova.

From 4,500 to 7,500 m: Miliolinella legis Saidova.

Tropics-Southern Subtropics

Sublittoral Zone: Nubecularia lucifuga Defranse, N. bradyi Millett, Quinqueloculina irrequieta Saidova, Q. vanimensis Saidova, Q. annectens (Schlumberger), Q. transversestriata (Brady), Q. bosciana (Orbigny), Q. samoensis Cushman, Articulina furacis Saidova, Spiroloculina subcostifera Saidova, S. crenata (Karrer), Flintina triquetra (Brady), Borelis melo (Fichtel et Moll), Saracenaria latifrons (Brady), Dentalina obiquestriata Reuss, Discorbis tabernacularis (Brady), D. opercularis (Orbigny), D. crustata Cushman, Glabratella pulvinata (Brady), Poroeponides lateralis Terquem, Robertina subculindrica (Brady), Planulina biconcava (Parker et Jones), Miniacina miniacea (Pallas), Rotalia venusta Brady, Schlumbergerella mayori Cushman, Sagrina lobatula (Brady), Bolivina abbreviata Cushman, Spirilling vivipara Ehrenberg.

Bathyal Zone

Upper Subzone: Ophthalmidium inconstans Brady, Quinqueloculina oklendensis Saidova, Q. funafutiensis (Chapman), Spiroloculina tenuisepta Brady, Nodosaria doliolaris Parr, Dentalina obliqua (Linnaeus), Vaginulina spinigera Brady, Sigmomorphina vitula Saidova, Discorbis tofuanus Saidova, D. williamsoni (Chapman et Parr), D. subbertheloti Cushman, Gyroidina planulata? Cushman et Renz, Baggina hauerii (Orbigny), Robertina declivis (Reuss), Cassidulinoides bradyi Cushman.

Lower Subzone: Quinqueloculina venusta Karrer, Vaginulina abyssorum Saidova, Holmanella sp. 1, Heterolepa alta Saidova, Cassidulina sp. 4, Patellinella ambulacrata (Moebius).

Southern Subtropics

Sublittoral Zone: Nubeculinella paschaensis Saidova, Quinqueloculina crassatina (Brady), Miliolinella australis (Parr), Sigmoilina conflexa Saidova, Frondicularia compta Brady, Discorbis piliolus (Orbigny), D. australis Parr, Rotalia? improvida Saidova, Siphonina parva Saidova, Cibicidina passiva Saidova, Carpenteria utricularis Carter, Buliminella elegantissima Orbigny var. fusiformis Sidebottom, Bulimina ornata Egger.

Bathyal Zone

Upper Subzone: Cibicides sp. 3, Rotamorphina sp. 2.

NOTAL REGION

Sublittoral Zone: Cornuspira tasmanica Parr, Ophthalmidium circularis (Chapman), Quinqueloculina villafrance Calvez, Q. crassatina (Brady), Cruciloculina subvalvularis (Parr), Astacolus altifrons (Parr), Pranularis sp. 15, Robulus sp. 20, R. articulatum (Reuss), Marginulina perobesa Parr, M. tesnersina Saidova, Dentalina translucens Parr, D. moratai Saidova D. subemaciata Parr, Guttulina oblonga (Orbigny)

Polymorphina exacuta Saidova, Discorbis lobatulus Parr, D. harmeri (Heron-Allen et Earland), Discorbis umbonifer Parr, D. snaers Saidova Valvulineria polita Parr, Gyroidina tesnaers Saidova, Eponides pusillus Parr, E. pacificus subsp. notalnus Saidova, Heronallenia laevis Parr, H. unduiculata (Sidebottom), Anomalina bassensis Parr, A. tasmanica Parr, Anomalinoides colligera Chapman et Parr, Cibicides subhaidingerii Parr, C. tesnaersinus Saidova, Laticarinata sp. 2, Parrellina imperatrix (Brady), Mississippina pacifica Parr, Ceratobuliminoides bassenses Parr, Buliminella basicostata Parr, Bulimina submarginata Parr, Cassidulina nonlimbata Saidova, Bolivina cincta Heron-Allen et Earland, Spirillina multispira Parr, S. pectinimarginata var. Aspinosa Parr.

Bathyal Zone

Upper Subzone: Quinqueloculina notalna Saidova, Pyrgo notalna Saidova, P. serratula (Cushman) subsp. imlimbus Saidova, Siphonodosaria sp. 1, Marginulina funis Saidova, M. gummi Saidova, M. Planata (Phleger et Parker), Vaginulina taleola Saidova, Guttulina taleola Saidova, Guttlina problema (Orbigny), Laryngosigma sanata Saidova, Planulina taxmanica Saidova, Discorbis, sp. 4, Annulopatellina harmeri Heron-Allen et Earland.

Lower Subzone: Ehrenbergina spinea Cushman.

ANTARCTIC REGION

Sublittoral Zone: Quinqueloculina ballenica, Mileolinella calcarata (Heron-Allen et Earland), Sigmoilina umbonata Heron-Allen et Earland, Sigmoilina umbonata Heron-Allen et Earland, Buccella antarctica Saidova, Epistominella antarctica Saidova, Pseudobulimina chapmani (Heron-Allen et Earland), Cibicides sp. 1, C. sp 2, C. lobatulus? (Orbigny), Virgulina sp., Cassidulina tuberculata Heron-Allen et Earland, Ehrenbergina spinea? Cushman, Spirillina vivipara? Ehrenberg.

Bathyal Zone

Lower Subzone; Marginulina albatrossi (Cushman).

STENOBATHIC SPECIES

The second group consists of stenobathic species that are restricted to a single specific vertical zone or subzone, but live in different latitude regions of the ocean. It consists of 223 species.

Sublittoral

Boreal Region

Northern Subtropics: Bucella subtenerrima Saidova, Robertina murotoensis Asano, Cibicides tuberculata Natland, Nonionella miocenica

Cushman var. *stella* Cushman et Moyer, *N. miocenica* Cushman, *Florilus grateloupi* (Orbigny), *Streblus beccarii* (Linnaeus), *Elphidium incertum* (Williamson), var. *lene* Cushman et McCulloch, *Nonionellina labradorica* (Dawson), *Cassidulina californica californica* (Cushman et Hughes).

Boreal Region

Tropics: *Ptychomiliola separans* (Brady), *Pyrgo sarcii?* (Schlumberger), *Pseudopolymorphina atlantica* Cushman et Ozawa, *Sigmomorphina trilocularis* (Bagg), *Polymorphina charlottensis* Cushman, *Elphidium translucens* Natland, *E. articulatum* (Orbigny), *E. tumidum?* Natland, *Cribroelphidium simplex* Cushman, *Planoelphidium jensenii* (Cushman), *Nonionellina punctata* (Orbigny), *Bolivina substriatula* Asano.

Boreal Region

Southern Subtropics: *Elphidiella hannae* (Cushman et Grant), *Buliminella elegantissima* (Orbigny), *Virgulina pauciloculata* Brady.

Boreal - Notal Region: *Marginulina costata* (Batsch), *Paramalina bilateralis* Leblich et Tappan, *Diocibicides biserialis* Cushman et Valentine, *Pullenia subcarinata* (Orbigny) subsp. *surtis* Saidova.

Northern Subtropics - Notal Region: *Cornuspiroides expansus* (Chapman), *Pateoris nampo* Saidova, *Spiroculina communis* Cushman et Todd, *Pyrgo sarsii* (Schlumberger), *Nodosaria simplex* Silvestri, *Amphicoryne falax* Jones et Parker, *Guttuline regina* (Brady, Parker Jones, *Discorbis patelliformis* (Brady), *D. subpatelliformis* Saidova, *Gyroidinoides miocenica* (Matter), *Eponides boninus* Saidova, *Heterolepa plana* Saidova, *H. positivus* Saidova, *Hanzawaia lucida* Saidova, *Notorotalia chathrata* (Brady), *Buliminoides williamsoniana* (Brady), *Uvigerina pseudoampulacea*, Asano, *Angulogerina spinipes* (Brady), *Brizalina compacta* (Sidebottom), *B. goesi* (Cushman), *Laterostomella spinea* (Cushman), *Patellina corrugata* Williamson.

Tropics - Notal Region: *Quinqueloculina oklendensis* Saidova, *Q. arenata* Saidova, *Sigmoilina obesa* Heron-Allen et Earland, *Triloculina lamellidens* Parr, *Pyrgo subpisum* Parr, *Lingulina bassensis* Parr, *L. grandis* Cushman, *Robulus popillosus* (Fichtel et Moll), *Marginulina angens* (Cushman et Todd), *Dentalina novaezealandica* Saidova, *Vaginulina* ex. gr. *bradyi* Cushman, *V. anemona* Saidova, *V. tasmanica* Parr, *Sigmoidella elegantissima* Parker et Jones, *Ramulina globulifera* Brady, *Pseudoglandulina radicula* (Linnaeus), *Discorbis concinna* (Brady), *Cancris auriculum* (Cushman), *Robertina tasmanica* Parr, *R. oceanica* Cushman et Parker, *Gavelinella ficaria* Saidova, *Laticarinata temuimargo* Brady subsp. *surtida* Saidova, *Astrononion allutus* Saidova, *Planogypsina inhaerens* (Schlutze), *Osangularia subdentata* Saidova, *Elphidium depressulum* (Cushman), *Baculogypsina sphaerulata* (Parker et Jones), *Cassidulina pacifica* Cushman.

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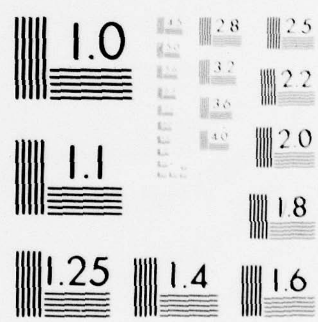

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Southern Subtropics - Notal Region: Robulus tasmanica Parr, Discorbinella biconcava (Jones et Parker) var. planoconcava (Chapman, Parr et Collins), D. disparilis (Heron-Allen et Earland), Karreria laevis Parr, Uvigerina nonperegerina Saidova, Bolivina bassensis Parr.

Notal - Antarctic Region: Pseudopolymorphina sororia Reuss, Angulogerina angulosa (Williamson) subsp. bassensis (Parr), Ehrenbergina Heron-Allen et Earland.

Sublittoral, Upper Bathyal Subzone

Boreal Region - Northern Subtropical: Fursenkoina bramlettei (Galloway et Morrey), Uvigerina peregrina subsp. peregrina Cushman, Angulogerina angulosa (Williamson) subsp. kokozuzaensis (Asano), Bolivina pseudodecussata Saidova, Bulimina exilis Brady.

Boreal Region - Tropics: Brizalina spissa (Cushman), Bermudezella komandorica Saidova, Angulogerina carinata Cushman, Cassidulina tortuso Cushman et Hughes.

Boreal Region - Southern Subtropics: Spiroloculina corrygata Cushman et Todd, Globobulimina auriculata Bailey subsp. orbiculata Saidova, Rectobolivina humilis (Cushman et McCulloch).

Boreal - Notal Regions: Brizalina pseudobeyrichi (Cushman).

Boreal - Antarctic Region: Cassidulina subcalifornica Droger.

Northern Subtropical - Notal Region: Robulus suborbicularis Parr, Dentalina vertebralis (Parr), Stomatorbina concentrica Parker et Jones, Astrononion viragoensis Cushman et Edwards, Nonion sollicitus Saidova, Buliminella millettii Cushman, Hopkisina karreriana (Brady) Bulimina marginata Orbigny, Siphogenerina columellaris (Brady), Ehrenbergina pacifica Cushman, Spirillina denticulata (Brady).

Tropical - Notal Region: Sigmoilina maniensis Saidova, Pyrgoella cabiata (Schlumberger), Nodosaria hirsuta Orbigny, Eponides tubulifera Heron-Allen et Earland.

BATHYAL

Upper Subzone

Boreal Region - Northern Subtropics: Robulus rotulata (Lamarck), Pseudoparella pacifica Cushman, Elphidium subincertum Asano, Cassidulina lomitensis Galloway et Wissler, Cassidella seminuda subsp. seminuda (Cushman).

Boreal Region - Tropics: Marginulina globra Orbigny.

Boreal Region - Southern Subtropics: Oridorsalis umbonatus (Reuss) subsp. tenerus (Brady), Heterolepa palpation Saidova, Pullenia subcarinata (Orbigny) subsp. alta Saidova, Bulimina patagonica Orbigny var. glabra Cushman et Wickenden, Uvigerina asperula Haidinger, Ehrenbergina trigona Goes subsp. iniculmena Saidova.

Boreal - Notal Region: Gyroidina soldanii Orbigny subsp. superior Saidova, Heterolepa planus subsp. modica Saidova.

Boreal - Antarctic Region: Discanomalina japonica Asano, Laterostomella subspinescens (Cushman).

160 Northern Subtropics - Notal Region: Quinqueloculina elongata Natland, Pyrgo murrhyna (Schwager) subsp. surtida Saidova, Nodosaria pyrula Orbigny, Robulus gibbus (Orbigny), Marginulina glabra Orbigny, Dentalina costai (Schwager), Gyroidina altispira Cushman et Stainforth, Cassidulina costatula subsp. costatula Cushman.

Northern Subtropics - Antarctic Region: Robertina subteres (Brady), Uvigerina ampullacea Brady subsp. infirmus Saidova.

Tropics - Notal Region: Miliolinella nowozealandica Saidova, Nodosaria raphanus (Linnaeus), Robulus limbosus (Reuss), R. clericii (Fornasini), R. calcar (Linnaeus), R. perrennis Saidova, Dentalina spirostriolata (Cushman), D. elegans Orbigny, D. submutsui Saidova, Vaginulina bassensis (Parr), V. tenuis (Bornemann), Siphonina pulchra Cushman, Cibicides robertsonianus (Brady), Laticarinata temuimargo Brady.

Tropics - Antarctic Region: Pseudoglandulina annulata (Terguem et Berthelin).

Lower - Upper Bathyal Subzones

Boreal Region - Northern Subtropics: Fursenkoina subcornuta Saidova, Bulimina mexicana Cushman, Cassidulina subtranslucens Saidova.

Boreal Region - Northern Subtropics: Triloculina prolatio Saidova, Nodosaria calomorpha Reuss, Bulimina spinifera Cushman, Brizalina oceanica (Cushman).

Boreal Region - Southern Subtropics: Globofulimina auriculata Bailey subsp. elongata (Cushman), Cassidella seminuda (Cushman) subsp. aequa Saidova, Sphaeroidina bulloides Orbigny.

Boreal - Notal Region: Nodosaria inflexa Reuss, Robulus tropicus Saidova, Dentalina sidebottomi Cushman, Fersenkoina subdepressa (Brady), Bulimina inflata Sequenza, Pleurostomella acuminata Cushman.

Boreal - Antarctic Region: Sigmoilina edwardsi (Schlumberger), Gyroidina orbicularis Orbigny, Laticarinina p a perata (Parker et Jones), Pullenia bulloides Orbigny, Rupertina stabilis (Wallich), Fursenkoina complanata (Egger).

Northern Subtropics - Notal Region: Cibicides lobulatus (Walker et Jacob).

Northern Subtropics - Antarctic Region: Pseudoglandulina laevigata (Orbigny), Angulogerina angulosa (Williamson) subsp. ornata (Cushman).

Tropics - Notal Zone: Pyrgoella sphaera (Orbigny).

Lower Bathyal Subzone

Boreal Region - Northern Subtropics: Heterolepa sp.

Boreal Region - Tropics: Eponides? tumidus (Brady).

Boreal - Notal Region: Pyrgo murrhyna (Schwager) subsp. profundus Saidova, Heterolepa vehemens subsp. altus Saidova, Bulimina rostrata Brady, Uvigerina curticosta Cushman subsp. dirupta Saidova, Favocassidulina favus (Brady), Cassidella perscicula Saidova.

Boreal - Antarctic Region: Dentalina neugeboreni (Schwager), Gyroidina soldanii Orbigny subsp. profundus Saidova, Alabamina weddellensis Earland, Alabaminoides exigus (Brady), Heterolepa plana subsp. convexa Saidova, H. profunda Saidova, Melonis pompilioides (Fichtel et Moll), Cassidulina subglobosa Brady, Ehrenbergina hystrix Brady.

161 Northern Subtropics - Notal Region: Quinqueloculina profundus Saidova, Pyrgo serrata (Brady), Siphonodosaria abyssorum (Brady), S. lepidula (Schwager), Saracenaria insitiva Saidova, Globulina cuspidata (Brady), Pyrulina extensa (Cushman), Plegeria hyalina Loeblich et Tappan, Oridorsalis umbonatus (Reuss) subsp. surtis Saidova, Heterolepa densus Saidova, Fursenkoina subbuchiana Saidova, Ehrenbergina trigona subsp. trigona Goes, Bolivina (Brizaline) decussata Brady, Bolivinita cellara Saidova.

Northern Subtropics - Antarctic Region: Pyrulina angusta (Egger), Gyroidina pulisukensis Saidova, Oridorsalis umbonatus (Reuss) subsp. profundus Saidova, Alabamina pygmaea (Hantken), Cibicides altus Saidova, Pullenia subcarinata (Orbigny) subsp. praealta Saidova, Cassidulinoides tenuis Phleger et Parker, Cassidulina crassa Orbigny subsp. pulchra Saidova.

Tropics - Notal Region: Quinqueloculina orifundissima Saidova, Eponides patagonica (Orbigny), Anomalinoides concinus Saidova, Heterolepa subfumens Saidova, H. fragosa Saidova.

Tropics - Antarctic Region: Robulus profundus Saidova, Planulina pacifica Saidova, Pullenia plana Saidova, Elphidium advenum (Cushman) Uvigerina curticosta Cushman subsp. infirma Saidova.

Notal - Antarctic Region: Cibicides corticata (Earland).

ABYSSAL ZONE

Boreal region - northern subtropics: Involvohauerina globularis Loeblich et Tappan.

Summarizing data obtained on the endemic aspect of secretionary bottom foraminiferal species in the Pacific Ocean (table 24), one can see that most endemic species occur in the sublittoral zone of the tropics and that the number of endemic species decreases with depth everywhere.

DISTRIBUTION OF SPECIES OF SECRETIONARY FORAMINIFERA

In the Pacific Ocean, secretionary bottom foraminifera are represented by 204 genera. All the genera, as well as species, can be assigned to three main groups.

The first group consists of genera characteristic only of specific latitude regions and vertical zones. It contains 65 genera. In the tropical region is a group of genera characteristic of the sublittoral zone as well as of the upper bathyal subzone. It contains 17 genera. Their distribution is given below by latitude and vertically (table 25).

The Boreal Region

Sublittoral zone: Protoelphidium genus.

Bathyal zone: the genera Lenticulina and Chilostomellina.

Tropical Region

Northern subtropics: Sublittoral zone: the genus Nonion.

Tropics Sublittoral: the genera Spirophtalmidium, Miliola, Tubinella, Wiesnerella, Idalina, Vertebralina, Monolisidium, Archaias, Orbitoletes, Alveolinella, Tristix, Nummulities, Cymbaloporella, Semirosalina, Epistomaroides, Cushmanella, Bifarinella, Trimosa, Orthoplecta, Nodogenerina, Conicospirilina.

Bathyal Zone

Upper Subzone: the genera Pyrulinoides, Planorbulina, Pavonina, Elipsoidina.

<table>
<tr><th colspan="2" rowspan="3">Zone</th><th colspan="11">Region</th><th rowspan="3">Omni-
lati-
tudinal
species</th><th rowspan="3">Total</th></tr>
<tr><th rowspan="2">Boreal</th><th colspan="6">Tropical</th><th rowspan="2">Notal</th><th rowspan="2">Ant-
arctic</th></tr>
<tr><th colspan="2">Northern
Sub-
tropics</th><th colspan="2">Tropics</th><th colspan="2">Southern
Sub-
tropics</th></tr>
<tr><td colspan="2" rowspan="3">Sublittoral</td><td rowspan="3">26</td><td colspan="2">52</td><td colspan="2">195</td><td colspan="2">13</td><td rowspan="3">41</td><td rowspan="3">13</td><td rowspan="3">88</td><td rowspan="3">558</td></tr>
<tr><td colspan="3">80</td><td colspan="3">28</td></tr>
<tr><td colspan="6">22</td></tr>
<tr><td rowspan="6">Bathyal</td><td rowspan="3">upper</td><td rowspan="3">15</td><td colspan="2">7</td><td colspan="2">90</td><td colspan="2">2</td><td rowspan="3">13</td><td rowspan="3">—</td><td rowspan="3">70</td><td rowspan="3">313</td></tr>
<tr><td colspan="3">24</td><td colspan="3">15</td></tr>
<tr><td colspan="6">6</td></tr>
<tr><td rowspan="3">lower</td><td rowspan="3">13</td><td colspan="2">3</td><td colspan="2">32</td><td colspan="2">—</td><td rowspan="3">1</td><td rowspan="3">2</td><td rowspan="3"></td><td rowspan="3">119</td></tr>
<tr><td colspan="3">5</td><td colspan="3">6</td></tr>
<tr><td colspan="6">7</td></tr>
<tr><td colspan="2">Abyssal</td><td>—</td><td colspan="2">—</td><td colspan="2">1</td><td colspan="2">—</td><td>—</td><td>—</td><td>1</td><td>2</td></tr>
<tr><td colspan="2">Total</td><td>54</td><td colspan="2">62</td><td colspan="2">318</td><td colspan="2">15</td><td>55</td><td>15</td><td>235</td><td>—</td></tr>
</table>

Table 24. Number of endemic species of secretionary bottom foraminifera in the Pacific Ocean. 162

Zone		Region				Omni-latitudinal species	Total
		Boreal	Tropical	Notal	Antarctic		
Sublittoral		1	46	2	—	17	66
—			17			26	
Bathyal	upper		4	2	—		6
—		1	2			7	
	lower		6	—	—	5	11
Total		2	75	4	—	35	—

Table 25. Quantity of endemic genera of secretionary bottom foraminifera in the Pacific Ocean

Lower Subzone: the Genera glandulina, Siphoglobulina, Astegerinata, Elipsoglandulina.

Sublittoral Zone: the genus Nubeculinella.

163 The following genera are endemic to the whole tropical region:

Sublittoral Zone: Nubecularia, Spirosigmoilina, Flintina, Nodobaculariella, Peneroplis, Borelis, Polymorphinella, Baculogypsina, Baculogypsinoides, Schlumbergerella, Dimorpha, Operoculina, Siderolites, Heterostegina, Cycloclypeus, Acervulina, Gypsina, Planorbulinella, Carpenteria, Miniacina, Cribroeponides, Glabraltella, Sigmovirgulina, Chrysalidinella, Schubertia, Bolivinella.

Bathyal Zone

Upper Subzone: Parella, Allomorphina.

Lower Subzone: Rotamorphina.

NOTAL REGION

Sublittoral Zone: Mississipina, Ceratobuliminoides.

Upper Bathyal Subzone: Laryngosigma, Annulopatellina.

The second group consists of stenobathic genera confined to a specific vertical zone but found in different latitude regions of the ocean. It contains 27 genera. Twenty-six genera are typical of the sublittoral and upper bathyal subzone.

Sublittoral Zone: Pateoris, Lingulina, Amphicorina, Pseudopolymorphina, Polymorphina, Ramulina, Nonionella, Cribroelphidium, Elphidiella, Parellina, Planoelphidium, Discorbinella, Cancris, Buccella, Karreria, Buliminoides, Pattelina.

Bathyal Zone

Upper Subzone: Rupertia, Epistominella, Planulina, Bolivinita, Chelostomella, Sphaeroidina, Pleubstomella.

Lower Subzone: Globulina, Pyrulina, Plegeria, Favocassidulina, Patellinella.

Sublittoral Zone

Upper Subzone: Cornuspira, Planispirina, Ophtalmidium, Massilina, Articulina, Phychomiliola, Nubeculina, Astacolus, Guttulina, Sigmoidella,

sigmomorphina, *Florilus*, *Streblus*, *Notorotalia*, *Nonionellina*, *Bermudezella*, *Discorbis*, *Siphonina*, *Pseudoparella*, *Stomatorbina*, *Heronallenia*, *Robertina*, *Anomalina*, *Buliminella*, *Uvicosiphonia*, *Spirillina*.

The third group consists of eurybiontic species found in all latitudes and different depths of the ocean. Their upper habitat boundary of these species always extends into the sublittoral zone. However, the lower habitat boundary of 20 genera reaches the extreme habitat boundaries of the bottom foraminifera (*Pyrgo*, *Pyrgoella*, *Sigmoilina*, *Siphonodosaria*, *Saracenaria*, *Dentalino*, *Pseudoglandulina*, *Melonis*, *Elphidium*, *Gyroidina*, *Anomalinoides*, *Hanzawaia*, *Pullenia*, *Astrononion*, *Bulimina*, *Uvigerina*, *Cassidulina*, *Cassidulinoides*, *Ehrenbergina*, *Bolivina*). The lower habitat boundary for another 12 genera descends deeper in the tropics and rises gradually, toward north and south, to the sublittoral zone or upper bathyal subzone (*Miliolinella*, *Spiroloculina*, *Nodosaria*, *Vaginulina*, *Rotalia*, *Pseudobulimina*, *Siphogenerina*, *Brizalina*, *Bifarina*, *Globobulimina*, *Angulogerina*, *Siphogenerina*). It seems that these genera need relatively high water temperatures at great depths, otherwise they are unable to absorb calcium for shell construction.

Average specimen content graphs and quantitative species distribution graphs were constructed for individual genera of secretionary bottom foraminifera that inhabit many latitudes of the Pacific Ocean and are represented by large numbers of specimens there.

The genus *Quinqueloculina* occurs in all regions of the Pacific Ocean. It occurred in the boreal region in an insignificant number
164 of species. The largest number of species (3 to 4 species) occurred at 50 to 300 m depths (28 shell specimens at 2° to 5°C water temperature). More species of this genus (up to 8 or 9) occur in the northern subtropics than in the boreal region at the same depths. These species are represented here by 261 specimens at water temperature of 10° to 20°C. Only individual species occur below depths of 300 m. In the tropics, the number of species and specimens of this genus increases sharply. At depths less than 500 m 18 to 31 species and up to 2,000 to 4,000 specimens live in water temperatures above 15° to 20°C. Below 500 m, the number of species and specimens decreases to single ones. In the southern subtropics and notal region the greatest number of species (5 species) occurred at 100 to 300-m depths, represented by 800 to 1,000 specimens at water temperatures of 15° to 20°C in the southern subtropics, and 5° to 10°C in the notal region.

From the above data, it is clear that even though representatives of this genus are found everywhere, depths of 0 to 300 m and water temperatures above 10°C are most favorable for them. At water temperature of 5° to 15°C, only a small number of species are represented by large quantities of specimens, but there are few species and specimens when the temperature is lower.

The genus *Spiroloculina* is represented in the boreal region by single species and specimens at less than 300 m depths. The number of species at these depths in the northern subtropics increases to 5, the number of specimens to 44. There are more species in the tropics than in other ocean regions, especially at 500 m where their number reaches 9 to 10 and the number of specimens reaches 300 to 500. Below 500 m, only individual species occur. In the southern subtropics, one encounters single species of genus *Spiroculina*, but at 100 to 300-m depths, they sometimes have up to 300 specimens. From the above material it can be seen that conditions favorable for genus *Quinqueloqulina* also favor *Spiroculina* and both have the same distribution pattern.

The genus *Nodosaria* occurs as individual species and in small numbers of specimens everywhere in the Pacific, except the tropics. In the tropics, the number of species increases sharply to 9 to 12 at depths greater than 200 m and reaches a maximum at 200 to 1,250-m depths, where water temperatures are 5° to 10°C. The largest number of specimens of this genus (about 280) occur at depths of 200 to 300 m and water temperatures of 10° to 15°C. At water temperatures below 5° and above 20°C, only single species and specimens are found.

The genus *Lobulus* was found in all regions of the Pacific Ocean. In the boreal region, this genus always was found in the form of individual species and specimens. In the northern subtropics, only individual species occur, but at 100 to 300-m depths they number up to 282 specimens. In the tropical regions, the number of species jumps to 13 to 19 at 300 to 1,250-m depths, while at 300 to 500-m depths they are represented by 7,500 specimens in water temperatures of 8° to 15°C. In the southern subtropics and notal and Antarctic regions only individual species of this genus occur. But the number of specimens in some places is significant; for example, in the notal region in 200 to 400-m depths and water temperatures of 5° to 10°C, up to 400 specimens are found. Thus, 300 to 1,250-m depths and water temperatures of 8° to 15°C are most typical for members of this genus. In lower and higher water temperatures, the number of species decreases, but larger numbers of specimens (200 to 300) sometimes are present. At water temperatures below 8° and above 15°C, only individual species and specimens are found.

The genus *Dentalina* was found in the form of individual species in all regions of the ocean. The greatest number of species (7 species) occurred in the tropics at 400 to 1,500 m depths, but many specimens (319 spcm) were at depths of 300 to 500 m. Consequently, one observes in this genus the same divergence between the depth of maximum species quantity and of maximal specimen content, as in the genera *Nodosaria* and *Robulus*. Favorable conditions for this genus are the same as for the other two.

Species of the family Polymorphinidae occur in greatest numbers at 100 to 500-m depths and the greatest number of specimens occur at 300 to 500-m depths.

In places at great depths, the few deep-water species, of all the genera and families mentioned above, are represented by a considerable number of specimens, which however, never reaches the population density attained by shallow-water species.

The genus Elphidium appears in all regions of the Pacific Ocean. Especially large numbers of species and specimens (of this genus) are found at depths of 100 to 4,000 m and in water temperatures of 10° to 15°C in the northern subtropics. There may be many species at higher temperatures, but their population densities are small, whereas at lower temperatures, there are only individual species, which, in places, have large numbers of specimens.

The genus Uvigerina was encountered in all regions of the Pacific Ocean. The largest number of species occur in the northern subtropics at depths of 100 to 500 m and water temperatures of 10° to 15°C (there are no data on population density), while in the tropics, at the same depths, but at water temperature of 10° to 20°C this genus has a high population density. At higher temperatures, there are many species but few specimens, while at lower temperatures, there are few species, but huge numbers of specimens occur at greater depths, especially in the northern subtropics at depths of 1,500 to 2,500 m and in water temperatures of 2° to 3°C.

The examples mentioned show quite clearly that the most favorable habitat conditions can be defined for widespread genera that occur in largest number of species with the greatest population densities. At water temperatures above the most favorable ones, the number of specimens usually decreases, while the number of species remains high. At water temperatures below those that favor a given genus, the number of species usually decreases sharply, while the number of specimens remains high.

This proves that most species of a given genus can adapt to water temperatures higher than optimum, but they produce few offspring in such cases. Only individual representatives of a genus can adapt to water temperatures lower than optimum and these species usually produce large populations in such cases.

DISTRIBUTION OF ORDERS OF SECRETIONARY FORAMINIFERA

Contemporary Pacific Ocean foraminifera with secretionary shells belong to the orders Miliolida, Lagenida, Rotaliida, Nummulitida, Buliminida, and Heterochelicida. In the Pacific Ocean, the last order

is represented by one species and a few specimens. Among the orders, the species of the orders Miliolida (35 to 40%) and Rotaliida (30%) predominate at depths less than 200 m; species of the orders Lagenida (18 to 20%), Rotaliida (24 to 29%), and Buliminida (27 to 37%) predominate at depths of 200 to 1,500 m, and only species of Rotaliida (30 to 35%) and Buliminida (37 to 43%) predominate at 1,500 to 3,500-4,500 m. The percentage content of species by orders relative to all species of secretionary foraminifera, is given in table 26. Species of the family Spirillinidae, whose taxonomic position is not quite clear, were also included in this table.

166 From the given percentage content of species of different orders, one can see that the oldest and most primitive secretionary foraminifera belonging to the orders Miliolida and Lagenida have the largest number of species at shallow depths less than 1,500 m. Species of younger and more highly developed orders predominate at depths greater than 1,500 m. This indicates that mainly the highly developed secretionary bottom foraminifera were able to adapt to great depths with lower temperatures, i.e. the pattern here is the opposite of that for agglutinating foraminifera, in which mainly the older and more primitive representatives adhere to great depths.

The order Miliolida is characterized by different numbers of species and specimens in different regions of the ocean. It is represented by 37 genera and 300 species.

Similar quantities of numbers of species of the genus Miliolida were found at all depths in the boreal region. The greatest quantity of specimens occurred at 2,500 to 3,000-m depths. In the northern subtropics, at depths of less than 300 m, there are 5 to 10 times more species than at depths greater than 400 m. Here the greatest number of specimens occur in water temperatures of 10° to 20°C and salinities of 34 to 35‰.

Depths of 200 to 250 contain the largest number of species in the tropics. Here also the greatest quantity of specimens are found. Water temperature at these depths is 15° to 28°C and the salinity is 34.5 to 35 ‰. Below 500 m, the number of species of this order gradually decreases, and at depths greater than 1,500 m, the number of these species is reduced by 10 times. But these few species are represented, in places, by large quantities of specimens at depths of 3,000 to 3,500 m, in water temperatures of 1.5° to 1.7°C, and salinities of 34.55 to 43.69‰. At 500 to 3,000-m depths, there are few specimens of these foraminifera.

167 In the southern subtropics, one can see a picture of quantitative distribution of species and specimens of the genus Miliolida that is very similar to that of the southern subtropics. Only here the maximum quantity of deep0water shells is more sharply defined at 3,000 to

Table 26. Quantity of benthic secretionary species, orders, and families at various depths In the Pacific Ocean.

(in % of total quantity of secretion foraminifera)

Depth, m	Order						
	Miliolida	Lagenida	Rotaliida	Nummulitida	Buliminida	Incertaesedis	Spirillinidae
0-50	35.8	6.07	31.8	1.73	25.13	-	2.3
50-100	30.8	7.4	30.5	1.8	26.6	-	2.9
100-200	23.0	15.8	31.1	1.7	26.2	0.2	2
200-300	20.9	19.7	29.6	1.3	27	0.4	1.1
300-400	21.6	17.8	27.3	1.6	29.7	0.6	1.4
400-500	21.1	19.5	27.0	1.6	28.9	1.1	0.8
500-750	19.00	19.6	26.0	1.4	31.6	1.4	1.1
750-1000	18.2	21.1	24.2	0.6	33.7	1.6	0.6
1000-1250	15.6	22.2	23.5	-	36.6	2.1	-
1250-1500	17.5	18.0	25.4	-	36.9	1.8	0.4
1500-1750	13.3	11.6	30.4	-	42.5	2.2	-
1750-2000	11.9	10.7	32.1	-	42.8	2.5	-
2000-2250	10.0	8.6	35.7	-	43.6	2.1	-
2250-2500	10.4	10.4	36.6	-	40.3	2.3	-
2500-2750	11.1	11.1	33.3	-	42.5	2.0	-
2750-3000	11.7	12.5	34.4	-	38.3	3.1	-
3000-3250	9.9	14.9	35.5	-	37.2	2.5	-
3250-3500	9.4	14.5	35.9	-	36.7	3.5	-
3500-4000	8.9	16.7	34.4	-	37.8	2.2	-
4000-4500	9.0	16.7	35.9	-	38.4	-	-

3,500-m depths. In the notal region, unlike the subtropics, large quantities of these foraminiferal specimens occur at depths of 1,000 and, it seems, up to 2,000 m at water temperatures of 2.5° to 4°C and salinities of 34.5 to 34.6‰. From the standpoint of distribution of number of species with depth, the picture in the notal region is the same as in the subtropics, only the maximum number of species is somewhat deeper (100 to 300 m). In the Antarctic region, the pattern of species distribution by depth is close to that of the subtropics and notal region. Many species here occurred at depths of 200 to 500 m, i.e. the upper maximum here is somewhat deeper than in the notal region. In the Antarctic region, unlike in the subtropics and tropics, the deepest-water maximum of foraminiferal specimens is weakly defined here, as in the boreal region.

From the data mentioned, one can see (fig. 61) that shallow-water and warm-water conditions are typical for the overwhelming majority of species of the genus Miliolida. Zero to 400-m depths and water temperatures greater than 15°C are the most favorable for these species. Under these conditions, numerous species are represented by a large quantity of specimens. At lower temperatures, the number of species of Miliolida sharply decreases at greater as well as lesser depths. Some representatives of this order (at great and shallow depths) at temperatures of less than 15°C, may have numerous specimens, which however, are always 2 to 3 times fewer than at temperatures of 15°C. All this indicates that miliolid fauna in general love warm and shallow water. Individual species of the genera <u>Miliolinella</u>, <u>Spiroloculina</u>, <u>Quinqueloculina</u>, <u>Triloculina</u>, <u>Sigmoilina</u>, and <u>Pyrgoela</u> live at depths greater than 1,500 m.

The order Lagenida is represented in the Pacific Ocean by 33 genera and 250 species. The number of species is similar at all depths in the boreal region. The species are represented by the greatest quantity of specimens at 2,500 to 3,000-m depths. In the northern subtropics, the greatest number of species and specimens are
168 found in depths of 100 to 200 m at water temperatures of 10° to 15°C and salinities of 34.5 to 35.5‰. In the tropics, Lagenida are most numerous especially at depths from 300 to 750 m, where species and shells are very numerous. In this region, water temperature is 5.5° to 10°C, and salinity is 34.5 to 34.7‰. In the southern subtropics, similar numbers of species were found at all depths, but most species were at 500-to 750-m depths where water temperature is 5° to 10°C and salinity is 34.4 to 35‰. The largest numbers of specimens were at depths of 1,000 to 1,500 m in water temperatures of 4° to 5°C. In the notal region, many of these species occurred at 200 to 300-m depths, in water temperatures of 5° to 10°C, and salinities of 34.25 to 35‰. The largest number of specimens were found at depths of 1,000 to 1,500 m in water temperatures of 3° to 4°C. In the Antarctic region, the number of species and specimens is insignificant.

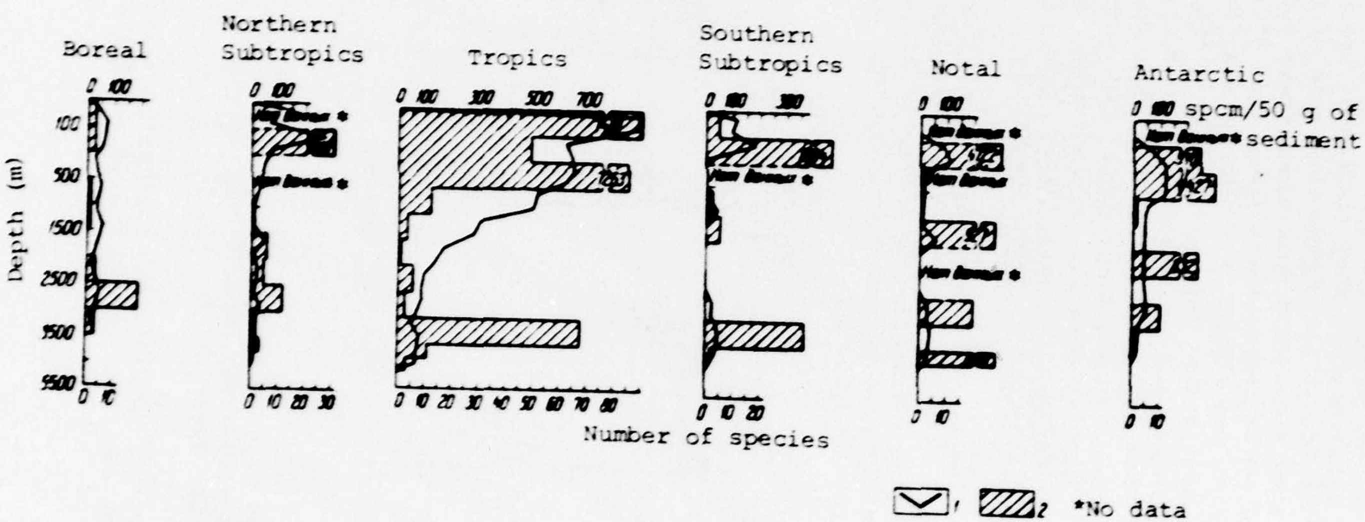

Fig. 61. Variation of numbers of species and specimens of the order Miliolida with depth in different zoogeographic zones of the Pacific Ocean.

1. number of species; 2. arithmetic mean content of specimens (stippled) in 50 g of dry sediment.

From the material presented, (fig. 62) it can be seen that the most favorable conditions for lagenids of the Pacific Ocean exist at 300-to 500-m depths and in water temperatures of 8° to 10°C. Under these conditions, the greatest number of species and specimens are found. At lower temperatures, they (lagenids) are represented, as a rule, by a few species at all depths, but some of them have many specimens, however, they are always four times fewer than at temperatures above 10°C. At water temperatures lower than 5°C, lagenid species occur singly and are fewest in great, as well as, shallow depths. All this indicates that representatives of the order Lagenida are generally shallow-water and warm-water forms. But they are more deep-water and cold-water loving than the miliolids, because the latter favor depths less than 400 m and water temperatures greater than 15°C. At depths greater than 1500 m, individual species of the genera Siphonodosaria, Planularis, Saracenaria, Viginulina, Globulina, Pyrulina, Pseudoglandulina, and Plogeria are found.

The order Rotaliida is represented by 75 genera and 495 species in the Pacific Ocean. In the boreal region, the number of species at all depths is similar and small. On the basis of specimen quantity, however, one can identify two maxima in this region; at depths of 100 to 300 m and 2,000 to 3,000 m.

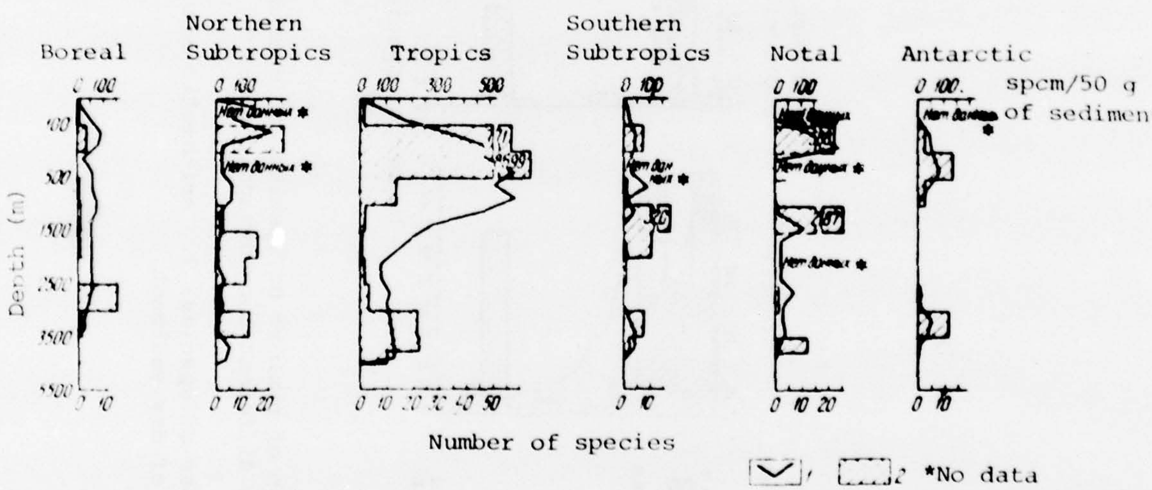

Fig. 62. Variation of number of species and specimens of the order Lagenida with depth in different zoogeographic regions of the Pacific Ocean.

1. number of species; 2. arithmetic mean content of specimens (stippled) in 50 g of dry sediment.

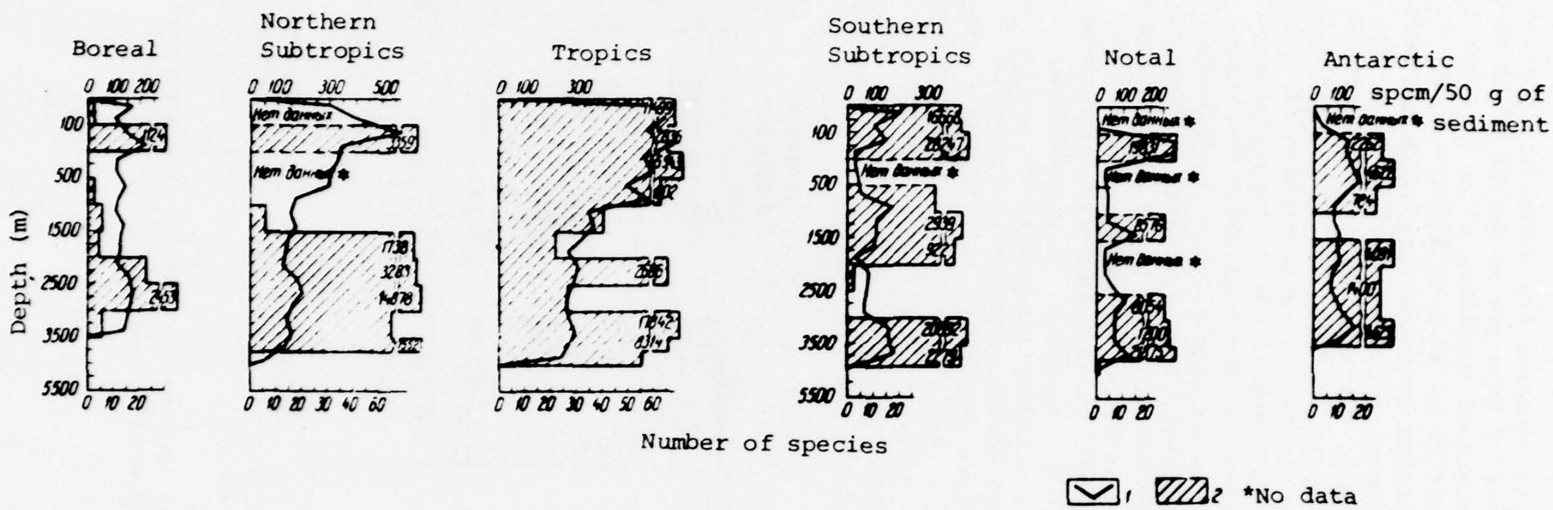

Fig. 63. Variation of number of species and specimens of the order Rotaliida with depth in different zoogeographic regions of the Pacific Ocean.

1. number of species; 2. mean arithmetic content of specimens (stippled) in 50 g of dry sediment.

In the northern subtropics, species are unevenly distributed with depth. The largest number of them are at depths of 50 to 200 m; and here the largest numbers of specimens occur at water temperatures of 10° to 20°C and salinities of 34.5 to 35‰. At 200-to 750-m depths, the number of species decreases gradually and here they are represented by few specimens, it seems. Below 750 m, the number of species decreases by a half, but the quantity of specimens increases sharply, especially at depths of 2,500 to 3,000 m and 3,500 to 4,000 m. In the tropics, extremely large numbers of species occurred at depths of less than 300 m and in water temperatures of 15° to 25°C, and higher. At depths of 400 to 1,000 m the number of species decreases gradually and deeper than 1,000 m it is 3 times smaller, but the quantities of specimens are very large in some places, especially at depths of 3,000 to 3,500 m, in water temperatures of 1.5° to 2°C, and salinities of 34.66 to 34.69‰. In the southern subtropics, species are few, but a relatively large number of species is found at depths of less than 200 m, 750 to 1,000 m, and 3,000 to 4,000 m. They are represented by the greatest quantity of specimens at approximately the same depths. In the distribution of species in the notal region, a pattern similar to that in the subtropics is seen. Few species of this order were found in the Antarctic region. The greatest number of them occurred at depths of 300 to 500 m and 3,000 to 3,250 m. At all depths, except 1,000 to 1,500 m, they are represented by a relatively large quantity of specimens (fig. 63).

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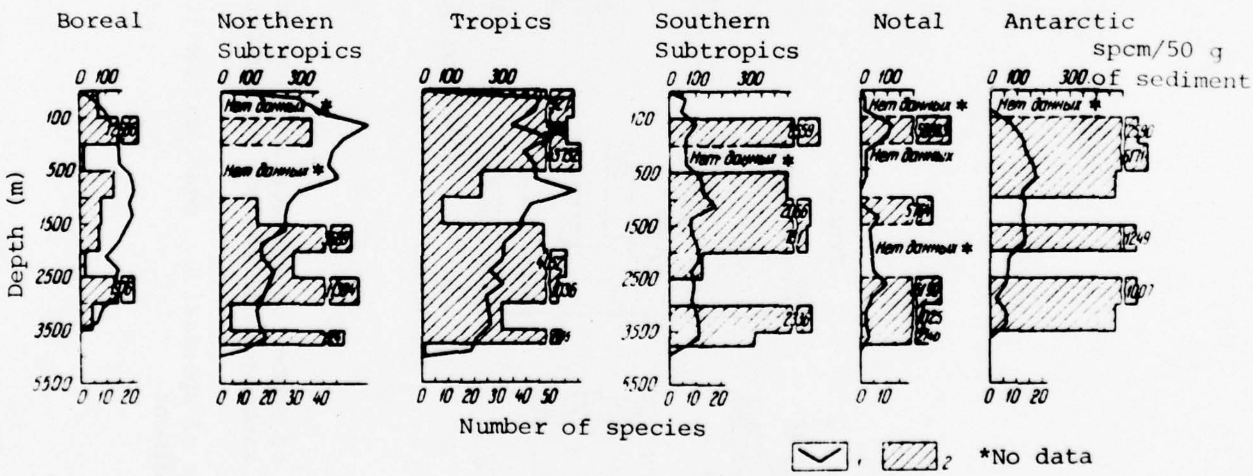

Fig. 64. Variation of the number of species and specimens of the order Buliminida with depth in different zoogeographic regions of the Pacific Ocean.

1. number of species; 2. Arithmetic mean content of specimens (stippled) in 50 g of dry sediment.

The distribution of the order Rotaliida by latitude and by depth demonstrates that depths less than 1,000 m and water temperatures greater than 10°C are most favorable for this order. At lower temperatures, the number of species decreases by 2 to 3 times, but the quantity of specimens at shallow as well as great depths, can be very large. Consequently, the order Rotaliida was represented by three faunas:

1. Warm-water and shallow-water rotaliid fauna consisting of many genera (table 25). Among the latter, Discorbis, Glabratella, Bagina, Cancris, Siphonina, Poroeponides, Gypsina, Rotalia, Amphistegina, and Anomalina occupy leading positions. The genus Cibicides also is represented here by a fairly large number of species and specimens. Water temperatures of 15° to 20°C are most favorable for this fauna.

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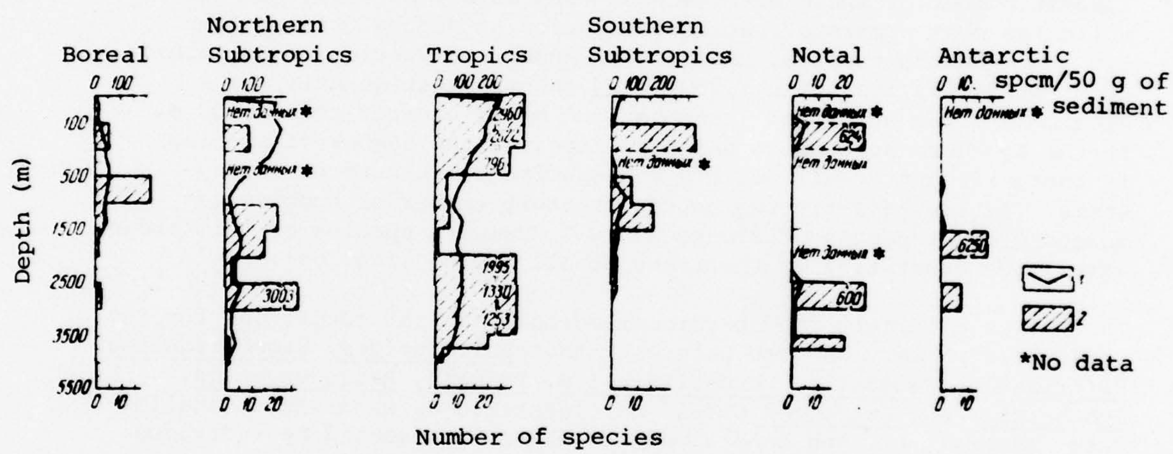

Fig. 65. Variation of the number of species and specimens of the family Bolivinitidae with depth in different zoogeographic regions of the Pacific Ocean.

1. number of species; 2. arithmetic mean content of specimens (stippled) in 50 g of dry sediment.

2. Temperate warm-water and shallow-water rotaliid fauna consist mainly of representatives of the genera Elphidium, Nonionella, Florilus, Nonionellina, and Cibicides. Water temperatures of 10° to 15°C are characteristic for this fauna.

3. Cold water fauna consist of representatives of the genera Gyroidina, Heterolepa, Oridorsalis, Melonis, and Alabaminoides. Water temperatures below 10°C are typical for this fauna.

The order Nummulitida is represented by 5 genera and 7 species in the Pacific Ocean. These foraminifera are not found in the boreal region. In the northern subtropics, individual species occur as single

specimens at 50 to 100-m depths. In the tropics nummulitids were found at depths less than 1,000 m. They occurred in largest numbers at depths less than 300 m and in water temperatures greater than 20°C. In the southern tropics and notal zone, individual specimens and individual species are encountered at depths less than 100 m. In contemporary ocean basins, representatives of this order belong to a relict fauna that is becoming extinct. It seems that in the past nummulitids were a very warm-water and shallow-water fauna.

The order Buliminida is represented by 37 genera and 200species in the Pacific Ocean. In the boreal region, the greatest number of species of this order occurred at depths of 500 to 1,500 m. Above and below these depths, they decrease in number. However, the greatest quantity of specimens of these foraminifera is found at depths of 100 to 300 and 2,500 to 3,000 m. In the northern subtropics, the largest number of these species was found at depths less than 750 m, while the most numerous specimens occurred at depths greater than 1,500 m. In the tropics, the largest number of species of Buliminida occur at depths less than 1,750 m and the greatest quantity of specimens occur at depths less than 500 m and greater than 1,500 m. In the southern subtropics and notal region, the number of species is insignificant at all depths, but specimens are numerous everywhere. In the Antartic region the greatest number of species was encountered at depths of 300 to 500 m. However, species of this order have large quantities of specimens at all depths (fig. 64).

It is difficult to determine favorable habitat conditions for the order as a whole. One can only note that Buliminoides, Sigmovirgulina, Bifarinella, Reussella, Chrysalidinella, Trimosa, Rectouvigerina, Schubertia, and Ortopleca should be classified as warm-water, shallow-
172 water genera. All the genera mentioned are represented by individual species. The remaining fauna of this order occur in great as well as shallow depths. The most cold resistant among them are representatives of the genera Buliminella, Fursenkoina, Globulimina, Uvigerina, Angulogerina, Cassidulina, and Ehrenbergina.

The family Bolivinitidae is represented by 4 genera and 80 species. The greatest number of species of this family was encountered in the northern subtropics and tropics at depths less than 400 m. The greatest quantity of specimens of these foraminifera was found at depths less than 500 and more than 2,000 m in the tropics, 2,500 to 3,000 m in the northern subtropics, and 1,500 to 2,000 m in the Antarctic region. Most of these are shallow-water and warm-water species. Depths less than 400 m and water temperatures greater than 15°C are typical of these species (fig. 65). Bolivinita is the deepest- and coldest-water genus among all genera of this family.

RELATIVE DISTRIBUTION OF ORDERS OF BENTHIC FORAMINIFERA

The percent correlation between species of different orders of bottom foraminifera varies in horizontally as well as vertically in the Pacific Ocean. The Pacific Ocean can be subdivided on the basis of the distribution of bottom foraminifera, as well as the distribution of other groups (Zernov, 1934; Gepner, 1936; Zenkevich, 1963), into four zoogeographic regions: boreal (north of 40°N), tropical (from 40°N to 40°S), notal (from 40° to 60°S), and Antarctic (south of 60°S). In the tropical region, one distinguishes the northern subtropics (from 40°N to 22°S), tropics (from 22°N to 22°S), and southern subtropics (from 22° to 40°S). Each region contains 3 vertical zones: sublittoral (depth less than 200 to 500 m), bathyal (depths 200 to 500 to 3,500 to 4,500 m), and abyssal (depths greater than 3,500 to 4,500 m). The bathyal zone is subdivided into two subzones: upper (200 to 500 to 2,000-m depths) and lower (2,000 to 3,500 to 4,500-m depths). The abyssal zone also is subdivided into two subzones: Abyssal (3,500 to 4,500 to 6,000 to 6,500-m depths) and ultra-abyssal (6,000 to 6,500-m to maximum ocean depths.

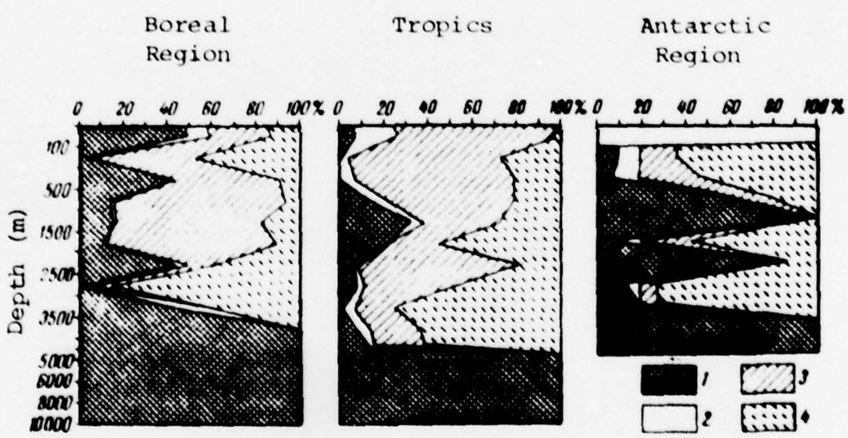

Fig. 66. Variation with depth in the Pacific Ocean of the percent content of benthic foraminiferal specimens with various shell composition and structure.

1. percent content of shells with agglutinated walls; 2. with secretionary calcitic porcelain walls; 3. with calcitic crypto-crystalline walls of radial structure; 4. with granular calcitic or microcrystalline walls of radial structure.

173 The percent of agglutinating and secretionary benthic foraminifera varies with latitude and depths in the Pacific Ocean. In shallow region, shells of agglutinating species comprise the greatest percentage (45%) of all the benthic foraminiferal shells in the boreal

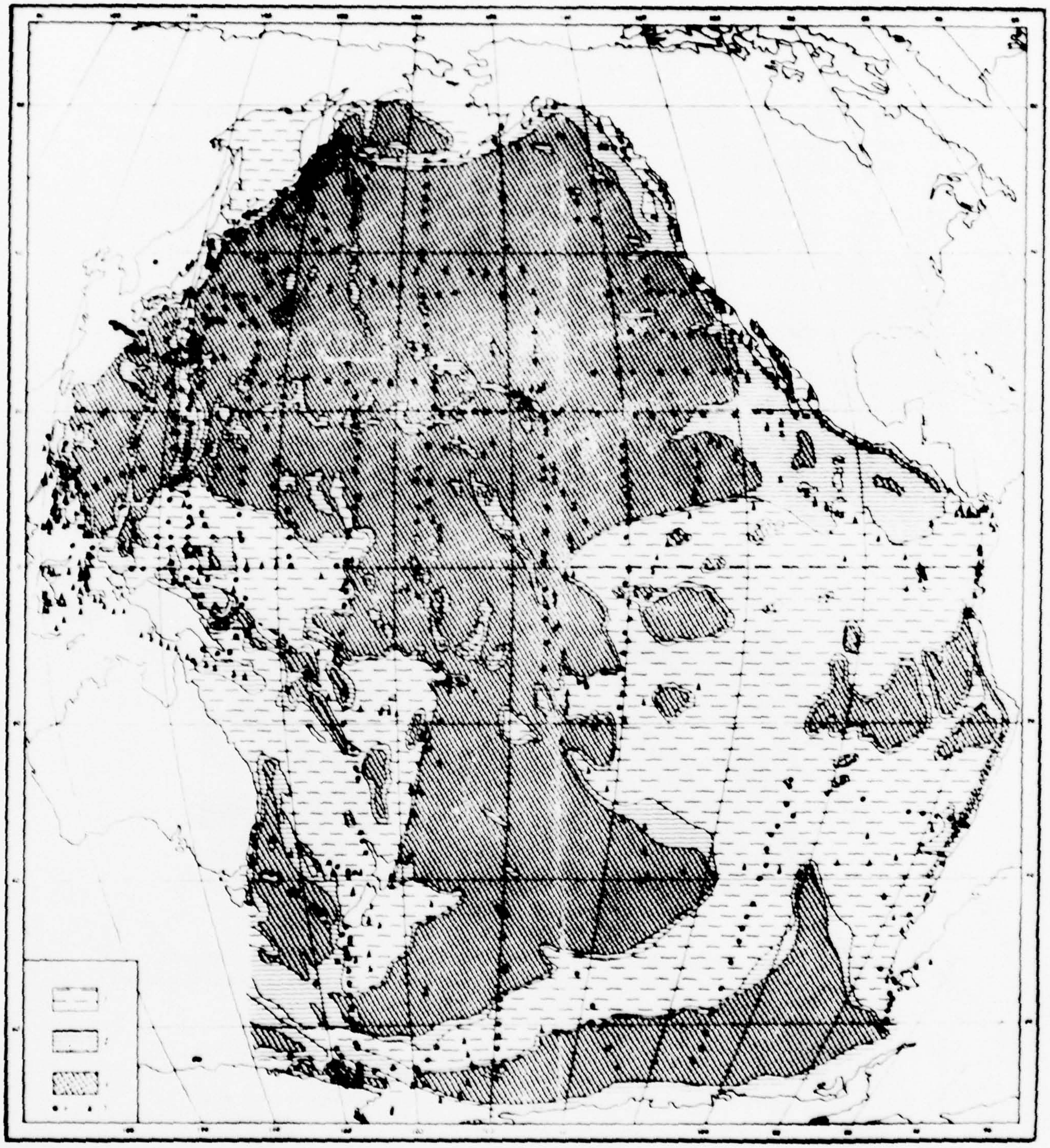

Fig. 67. Relative distribution of secretionary and agglutinating benthic foraminifera in the Pacific Ocean (in % of total quantity of samples).

1. less than 15% agglutinating and more than 85% of secretionary species; 2. 15-99% agglutinating, 1-85% secretionary species; 3. 1-0% agglutinating, 99-100% secretionary species; 4. Vityaz' and Ob' stations; 5. stations from foreign expeditions.

region at depths less than 100 m. In shallow areas of other regions, shells of these foraminifera comprise more than 10% (fig. 66). The author has no quantitative data for these depths in the notal and Antarctic regions.

On continental shelves and slopes, agglutinating foraminifera form the greatest percent at 1,000 to 1,500 m (90%) and 2,000 to 2,500 m (80%) depths in the Antarctic region and at 300 to 500 and 2,000 to 2,500-m depths (about 45%) in the boreal zone. In the tropics, the content of these foraminifera is about 30% at depths of 1,000 to 1,500 m. In the remaining continental and island shelf and slope areas, shells of agglutinating species comprise 10 to 15%.

Agglutinating species comprise almost 100% of shells in the ocean bottom, at depths greater than 3,500 m in the boreal and Antarctic regions and at depths greater than 4,500 m in the tropical and notal zones.

The chart of distribution of agglutinating and secretionary benthic foraminifera (fig. 67) shows that the Pacific regions of the Pacific Ocean are occupied mainly by agglutinating species. These regions form the central part of the ocean, and widen toward the north and narrows to the south. The southwestern and southeastern regions are occupied mainly by secretionary foraminifera. According to N. V. Belyayeva's data, sediments of the two regions mentioned contain the greatest quantity of shells of dead planktonic foraminifera.

Boreal Region

The Boreal region is characterized by the following features of foraminiferal distribution. Secretionary bottom foraminiferal live at depths less than 3,500 m in this region and comprise 60 to 75% of the total species of foraminiferal fauna. Among these, rotaliids and buliminids have the largest number of species (fig. 68). At depths of 300 to 2,500 m, the greatest percent of species are buliminids (25 to 37%). From 2,500 to 3,500 m, about 42 to 59% of the species are agglutinating foraminifera. Below 3,500 m, the foraminiferal fauna consist of agglutinating species, mainly astrorhizids, ammodiscids, and ataxophragmiids. The largest number of species of the orders Ammodiscida (16 to 20%) and Rotaliida occur at 0 to 300 m depths.

Secretionary species predominate in the sublittoral zone of the boreal region. These species comprise 61 to 69% of all species of foraminifera found in this region. Based on miliolid distribution, the lower boundary of the sublittoral zone is at 200 m, but based on lagenids and buliminids, this boundary is at approximately 300-m depths. Rotaliids predominate in a number of species (39%) at 0 to 50 m depths. Rotaliids and buliminids predominate (21 to 22%) at

50 to 200-m depths. The greatest quantity of shells in the sublittoral zone (fig. 69) are buliminids. In some places, at depths less than 100 m, up to 30% of the specimens are agglutinating foraminifera of the order Textulariida.

The upper bathyal subzone can be subdivided into 3 horizons. The 300-to 500-m horizon is characterized by many buliminid specimens (40%) and, among agglutinating foraminifera, ammodiscids (27%). It is impossible to determine the principal species of this horizon, because they all have similar quantities of specimens. It seems that this horizon is transitional between the sublittoral and bathyal zones. The 500-to 1,000-m horizon contains numerous specimens of buliminids and bolivinids, which comprise 86% here. The 1,000 to 1,500-m horizon is charact erized by many rotaliid (24.5%) and buliminid (58%) specimens.

The boundary between the upper and lower bathyal subzones is clearly identifiable from the percent relationship of rotaliid and buliminid specimens. Above 2,000 m, 40 to 86% of all shells are buliminids, while below 2,000 m, 40 to 50% are rotaliids.

The lower bathyal subzone also is subdivided into 4 horizons. The 1,500- to 2,000-m horizon is characterized by many rotaliid (34%) and buliminid (55%) specimens. It is difficult to distinguish the leading species at these depths, because there are similar quantities of specimens of all species and this horizon is transitional between the upper and lower subzones. The 2,000-to 2,500-m horizon is characterized by a predominance of rotaliid (41%) and, among agglutinating shells, ataxophragmiid (36%) shells. Rotaliids are represented by Heterolepa plana conveka and Melonis pompilioides, while ataxophragmiids are represented by different species with similar numbers of specimens. The 2,500-to 3,000-m horizon is characterized by the predominance of rotaliids (50%) and buliminids (40%). The 3,000-to 3,500-m horizon is dominated by ammodiscids (22%). rotaliids (25%) and buliminids (18%). All species of these orders have similar quantities of shells, i.e. this horizon is transitional to the abyssal zone.

Only agglutinating foraminifera occurred in the abyssal and ultra-abyssal zones. Ammodiscid species there predominate among these foraminifera. The former species comprise 43 to 50% of all species. The ultra-abyssal zone is characterized by a large quantity of specimens of ammodiscids (32%) and ataxophragmiids (83%).

Tropical Region

In this region, unlike the boreal region, secretionary bottom species were found at depths of 4,000 to 4,500 m.

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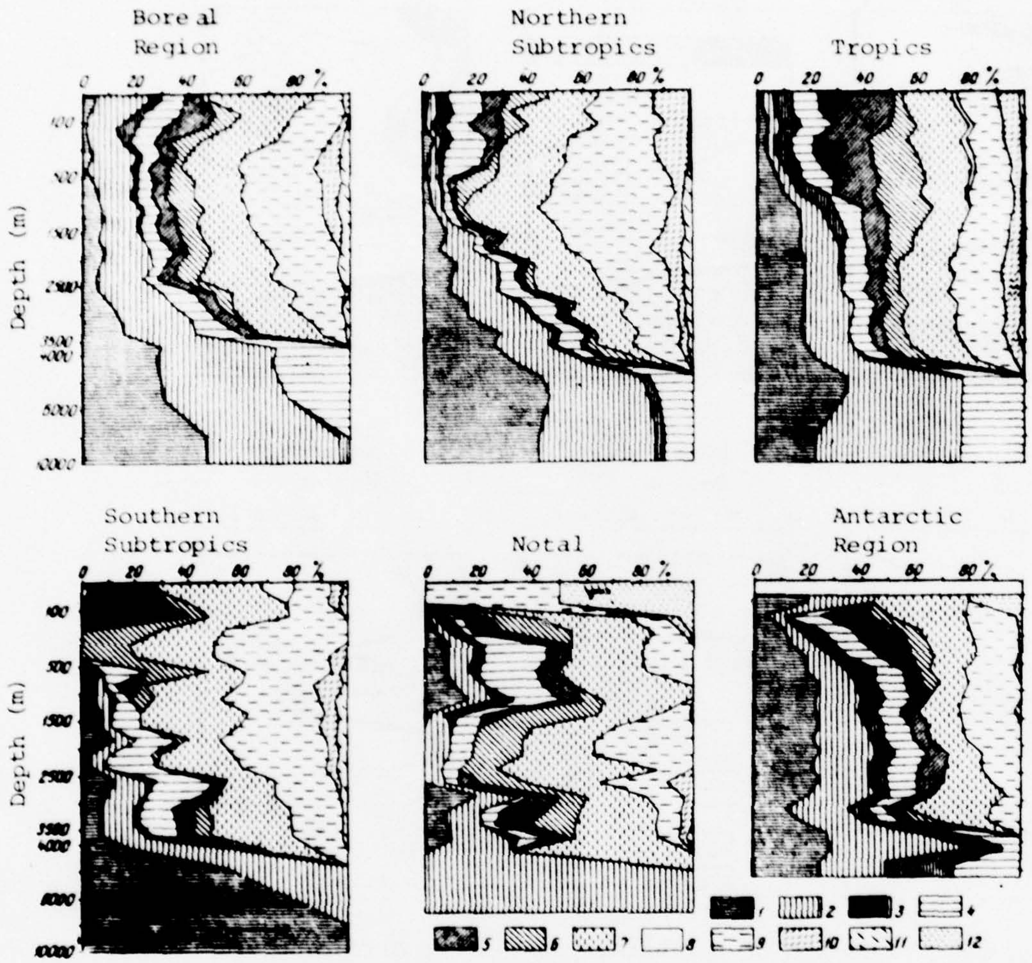

Fig. 68. Variation of percentage content of different orders and families of benthic foraminiferal species with depth in different zoogeographic regions of the Pacific Ocean.

1. Astrorhizida; 2. Ammodiscids; 3. Textulariida; 4. Ataxophragmiida; 5. Miliolida; 6. Lagenida; 7. Rotalida; 8. Nummulitida; 9. Buliminida; 10. Bolivinitidae; 11. Incertaesedis; 12. Spirillimidae.

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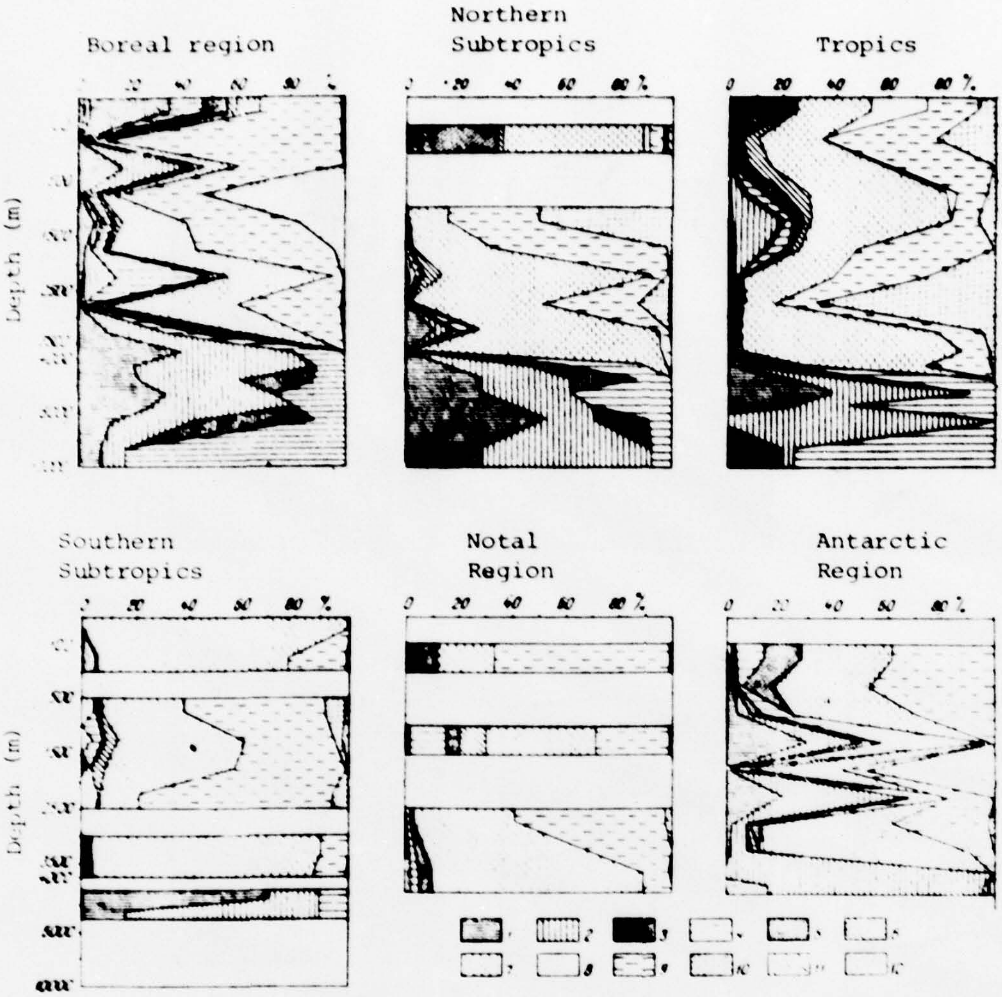

Fig. 69. Variation of percentage content of different orders and families of benthic foraminiferal specimens with depth in various zoogeographic regions of the Pacific Ocean.

1. Astrorhizida; 2. Ammodiscida; 3. Testulariida; 4. Ataxophragmiida; 5. Miliolida; 6. Lagenida; 7. Rotaliida; 8. Nummilotoda' 9. Buliminida; 10. Bolivinitidae; 11. Incertaesedis; 12. Spirrillimidae.

Northern Subtropics. At depths of less than 2,500 m, secretionary foraminiferal species comprise 75 to 90% of all foraminiferal fauna. These are mainly species of the order Buliminida. At 2,500-to 4,500-m depths the number of species of secretionary foraminifera decreases and they comprise only 18 to 66% of all species there. At these depths, species of ammoidiscids, rotaliids, and buliminids are present in similar quantities. Below depths of 4,000 to 4,500 m, occur agglutinating species belonging to the same orders as in the boreal zone.

Based on distribution of species of ataxiofragmiids and bolivinids, the lower boundary of the sublittoral zone can be placed at approximately 300-m depths, while based on miliolids, langenids, and buliminids it would be at a depth of about 200 m. The largest proportion of species of rotalids (24 to 27%) and buliminids (23 to 28%) occur at depths less than 200 m. The most numerous specimens among these genera are rotalids (52%).

The upper bathyal subzone can be subdivided into 3 horizons. We have no data on the quantity of shells in the 300-to 500-m horizon. Buliminid species are the most numerous here. The 500-to 1,000-m horizon contains rotaliid (26 to 29%) and buliminid (46 to 49%) species. We have no data on the quantity of species at these depths. The 1,000-to 1,500-m horizon contain mostly buliminids and bolivinids, whose shells comprise 85% of all shells found. Rotaliid (30%) and buliminid (66%) shells predominate in the 1,500-to 2,000-m horizon.

179 The percent correlation between species of different orders permits delineation of the boundary between upper and lower bathyal subzones at 1,250 m. Based on percent correlation of specimen contents, this boundary can be drawn for agglutinating foraminifera at the 1,500-m depth, while for secretionary foraminifera - at 2,000 m. Consequently, we assign depths less than 2,000 m to the upper subzone and those greater than 2,000 m to the lower bathyal subzone. Depths of 1,500 to 2,000 m seem to be transitional between upper and lower bathyal subzones.

The lower bathyal subzone can be subdivided, based on the dominance of shells of different orders, into 4 horizons. The 2,000 to 2,500 and 3,000 to 4,000-m horizons contain mainly rotaliids. They comprise 81 to 94% of all specimens here. The 2,500 to 3,000-m horizon contains almost equal numbers of rotaliid and buliminid specimens. The 4,000 to 4,500 m horizon is transitional relative to the abyssal zone. Here, all secretionary foraminifera are represented by a few specimens, comprising 8% of the total. In abyssal and ultra-abyssal zones, only agglutinating species are found. Most shells are astrorhizids at depths less than 6,000 to 6,500 m, deeper they are mainly ammodiscids.

The Tropics. In the tropics, unlike the northern subtropics and boreal regions, miliolids and lagenids predominate among the secretionary foraminifera in the faunal complex. The number of their species is quite large here. At depths less than 1,000 m, species of miliolids comprise 15 to 28% of all species. Lagenid species comprise 15 to 19% at depths of 200 to 1,750 m. There are 2 to 3 times fewer rotaliid and buliminid species in the tropics, but the number of these species, especially rotaliids, is high in individual horizons. At depths less than 1,000 m, agglutinating foraminiferal species comprise 21 to 29%, at 1,000 to 4,000 m 35 to 44%, and in depths greater than 4,500 m they comprised the entire foraminiferal fauna.

Based on the distribution of species of agglutinating foraminifera belonging to 3 orders, the lower boundary of the sublittoral zone can be drawn at about 400-m depths, but based on the distribution of species of one order of agglutinating and 4 orders of secretionary foraminifera, it should be at a depth of about 500 m. Three horizons can be identified in the tropic from the species population densities of various orders. The 0 to 100-m horizon is characterized by miliolid species which form 28% of all species in this region, and 18% of all shells. Nummulitid (21%) and rotaliid (28%) shells also comprise large proportions here. Miliolid (20 to 21%) and rotaliid (19 to 20%) species predominate in the 100 to 300-m horizon, while buliminids form the largest number of specimens (65%). In the 300 to 500-m horizon, miliolid (19 to 22%), lagenid (16 to 18%) and rotaliid (18 to 19%) species predominate. Only rotaliids (43%) and buliminids (41%) predominate in numbers of shells.

Based on the dominance of shells of different orders, the upper bathyal subzone can be divided into 2 horizons. The 500- to 1,500-m horizon consists mainly of rotaliids, which comprise 52% there. Buliminid shells (52%) predominate in the 1,500- to 2,000-m horizon.

The boundary between the upper and lower bathyal subzone can be placed at 1,750 m based on the distribution of species of textulariids, at 1,500 m based on miliolids, lagenids, and buliminids distribution, and at 2,000 m based on rotalids. Consequently, the author assigns depths less than 2,000 m to the upper subzone.

The lower bathyal subzone can be divided into 3 horizons based on shell correlations. Bolivinid shells (60 to 80%) predominate at
180 depths of 2,500 to 3,000 m, rotaliid shells (73 to 83%) at 3,000 to 4,000 m. Principally rotalid shells (45%) occur in the 4,000 to 4,500 m horizon. Only agglutinating species were found in abyssal and ultra-abyssal zones. Astrorhizid and ammodiscid shells predominate in the abyssal zone, ataxophragmiid shells - in the ultra-abyssal zone.

Southern subtropics. Based on percentage correlation of various orders, the southern subtropics occupy an intermediate position relative to the northern subtropics and tropics. As in the northern subtropics, many species in this region are buliminids (30 to 40%), especially at depths greater than 500 m. As in the tropics, large percemtages of miliolid (24 to 39%) and lagenid (30%) species occur at depths less than 750 m here. In the southern subtropics, unlike all northern regions, the percentage of ataxophragmiid species increases (up to 20 to 23%) at depths of 2,250 to 3,000 m.

In this region, based on the distribution of agglutinating foraminifera species, the lower boundary of the sublittoral zone is at a depth of 300 m, while based on secretionary foraminiferal species, it is at 200-m depths. Most foraminiferal shells found here are rotaliids. The upper bathyal subzone has mainly rotaliids, whose species comprise 23 to 36% (their shells comprise 34 to 49%), as well as by buliminids, whose species comprise 33 to 54%, and shells comprise 36 to 57%.

Based on the percentage correlation of species of different orders, the boundary between the upper and lower bathyal subzones can be drawn at depths of 1,250 to 2,000 m. Based on the content of ataxophragmiids, lagenids, and rotaliids it should be at about 1,250 to 1,500 m. The lower bathyal subzone can be divided into 2 horizons. The horizon at 2,000 to 3,500 m contains mainly rotaliid and buliminid species. Agglutinating species do not comprise more than 50% here, while in the 3,500 to 4,500-m horizon they already comprise about 70%. In the abyssal and ultra-abyssal zone, mainly astrorhizids are found.

Notal Region

Secretionary foraminifera live at depths less than 4,500 m in this region. Unlike more northern regions, buliminid (50%) and spirillinid (50%) species predominate at depths less than 100 m. Ataxophragmiid species (17 to 22%) become quite significant at 300 to 1,250-m depths, while lagenid species (18 to 33%) are significant at depths of 1,250 to 2,250 m. The percentage of rotaliid species here is the same as in the southern subtropics, but buliminids are somewhat fewer in some areas.

The lower boundary of the sublittoral zone, based on distribution of agglutinating foraminifera, is at approximately 300 to 400 m depths, but based on secretionary foraminifera, it is at 300 m. For depths of less than 100 m, we had no quantitative data for individual species. Biluminids comprised 66% of the shells at 100 to 300-m depths.

The boundary between upper and lower bathyal subzones is at about 1,250 m based on percentage correlation of astrorhizid, ataxophragmiid, and lagenid species, and only for buliminids can it be dropped to 1,500 m depths. Since we have no quantitative data on species at depths of 300 to 1,000 m and 1,500 to 2,500 m, the author conditionally assigns depths less than 1,250 m to the upper subzone and the k,250-m depth to the lower subzone.

181 ## Antarctic Region

In the Antarctic, secretionary species live at depths less than 3,500 m. At depths of less than 2,000 m, the greatest percentage among these species consists of buliminids, which are very dense there.

The peculiarity of the proportion of foraminifera in the Antarctic region is the large number of agglutinating foraminiferal species at depths less than 500 m. These species comprise 55 to 60% here, and their shells are very numerous at depths of 1,000 to 1,500 m (97.5%) and 2,000 to 2,500 m (84%).

It is difficult to determine the distributional boundary of lower sublittoral fauna in the Antarctic, because we have no data on foraminiferal fauna at depths less than 50 m, very little data for 50 to 100-m depths, and have quantitative data for species only at depths greater than 100 m. Rotaliid (40%) and agglutinating foraminiferal (40%) species predominate in the 50 to 100-m horizon. Rotaliid (28%) and buliminid (18%) species predominate in the 100 to 200-m horizon. Buliminid (39%) and rotaliid (33%) are the most numerous specimens here.

The upper bathyal subzone can be subdivided into 3 horizons. Buliminid shells (about 38 to 47%) are most representative of the 200 to 750-m horizon. The 750 to 1,500-m horizon contains mainly agglutinating foraminiferal shells (up to 97%). The 1,500 to 2,000-m horizon has a large quantity of bolivinid shells (59%).

Based on ammodiscid distribution, the boundary between the upper and lower bathyal subzones is at 1,500 m, but for buliminids - at 2,000 m. Based on variation of percentage content of shells of different orders, it should be about 2,000 m. The lower bathyal subzone is divided into 2 horizons. The 2,000 to 3,500-m horizon has shells of the ammodiscid order of agglutinating foraminifera, which comprise 46% here. The 2,500 to 3,500-m horizon is identified by rotaliid shells (49 to 78%).

From the standpoint of the quantity of species and specimens, the Antarctic region abyssal zone is represented mainly by ammodiscids.

FAUNA, TAXOCOENOSES, AND GENOCOENOSES OF BENTHIC FORAMINIFERA

Studies of the distribution of benthic foraminifera, based on quantitative and qualitative evaluation of fauna as well as statistical processing of the data, showed that different foraminiferal faunas and taxocoenoses are confined to specific latitude regions and vertical zones of the Pacific Ocean.

The number of species of various foraminiferal orders varies with depth as well as latitude. The percentage correlation of these species has revealed two principal oceanic faunas in the Pacific Ocean: sublittoral - bathyal and abyssal.

Abyssal fauna are distributed at depths greater than 3,500 to 4,500 m. They consist almost 100% of agglutinating foraminifera with arenaceous shells (fig. 70).

Sublittoral - bathyal fauna are distributed in all regions of the ocean where depths do not exceed 3,500 to 4,500 m. More than 50 to 60% consist of secretionary foraminiferal species with calcareous shells. Agglutinating species of foraminifera comprise less than 40 to 50% here. Cold-water, temperate, and warm-water fauna can be identified in the sublittoral-bathyal fauna.

182 Temperate sublittoral-bathyal fauna are distributed very widely in the Pacific Ocean. They occupy depths of 0 to 3,500 to 4,500 m in the boreal, subtropical, and notal regions. In the tropics, this fauna occurred only at 1,500 to 3,500 to 4,500-m depths. More than 60% of the species composition of this fauna belongs to the orders Rotaliida and Buliminida.

In the tropics, warm-water sublittoral-bathyal fauna were distributed at depths of 0 to 1,000 to 1,500 m. The content of species of the orders Miliolida and Lagenida increases in this fauna, and their proportion reaches the same value as species of the orders Rotaliida and Buliminida.

Cold-water sublittoral-bathyal fauna are distributed in the Antarctic region. Here the number of species of agglutinating foraminifera more than 50%. These species belong mainly to the orders Astrorhizida and Ammodiscida. Species with secretionary shells in this fauna belong mainly to the orders Rotaliida and Buliminida.

The author classified taxocoenoses on the basis of predominant proportions of shells of various orders and families of foraminifera. The percentage correlation was calculated from the arithmetic mean (stippled), oxygen content of the water and its saturation with $CaCO_3$.

The variable factor is the one most effective in any one case. Twenty-nine genocoenoses have been identified so far in the Pacific Ocean.

The identified oceanic taxocoenoses, genocoenoses, and their distributional features can be used in stratigraphic classification of marine deposits, facies analysis, and paleogeographic construction.

Only 5 oceanic bottom foraminiferal taxocoenoses can be identified in the whole Pacific Ocean: asterigerinid, buliminid, rotaliid-buliminid, alabaminid, and astrorhizid-ammodiscid (fig. 70). These taxocoenoses consist of genocoenoses with narrower distributions.

I. The Asterigerinid taxocoenoses occupies the tropical region of the ocean and descends to depths of 500 m in the subtropics and to 1,000 m in the tropics in the central part of the ocean. A water temperature of 10° to 25°C characterizes this taxocoenosis. This taxocoenosis consists of 6 genocoenoses:

1. The Nummulitid-miliolid genocoenosis is distributed through the tropics at depths less than 100 m, in water temperatures of 25° to 28°C, and oxygen content of approximately 4 ml/1. This is the warmest-water genocoenosis of all benthic foraminiferal genocoenoses. Nummulitids are represented there by the genera Operculina, Heterostegina, and Schlumbergerella. Their shells comprise 21% of all specimens found in this genocoenosis. The miliolids are represented by 89 species, mainly belonging to the genus Quinqueloculina, whose shells form 18% (of the total). Shells of genus Amphistegina comprise 15%. The remaining foraminifera are represented by a few specimens.

2. The Miliolid-amphistegid genocoenosis occurred in the northern subtropics in 100 to 300-m depths, water temperatures of 10° to 20°C, and oxygen contents of about 5 ml/1. The miliolids are represented mainly by the genus Quinqueloculina, whose shells comprise 29° of this genocoenosis, shells of two species of genus Amphistegina comprise 18%. Representatives of genus form Cibicides form a significant number of specimens whose shells comprise 15% (of the total).

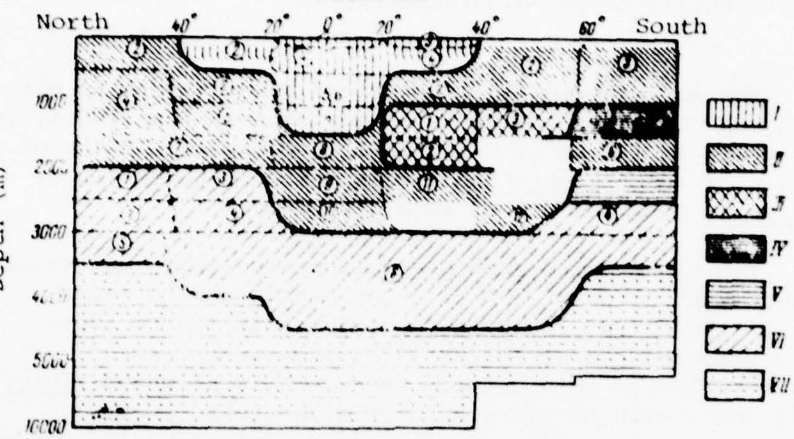

Fig. 70. Taxocoenoses and genocoenoses of benthic foraminifera and their distribution in the Pacific Ocean.

I. Asterigerimid taxocoenosis. Numbers in circles denote genocoenoses:

1. hummulido-miliolid; 2. miliolid-amphisteginid; 3. amphisteginid-planogepsid; 4. cibicid-amphisteginid; 5. amphisteginid; 6. heterolepid

II. Buliminid taxocoenosis. Numbers in circles denote genocoenoses:

2. cassidulid; 3. cassidulid-alabaminid; 4. bolivinid; 5. bolivinid-uvigerinid; 6. bolivinid-globobuliminid; 7. uvigerinid; 8. cassidulinid-uvigerinid; 9. cassidellid-buliminid; 10. cassidelid; 11. buliminid; 12. ehrenberginid-cassidulinid

III. Rotaliid-buliminid taxocoenosis. Circles numbers denote genocoenoses:

1. buliminid-nonionid; 2. buliminid-oridorsalisid; 3. heterolepid-cassidulinid

IV. Trochamminid genocoenosis

V. Cyclamininid-cassidulinid genocoenosis

VI. Alabaminid taxocoenosis. Circled numbers denote genocoenoses:

1. oridorsalid-eggerellid; 2. oridorsalid-ehrenberginid; 3. oridorsalid-alabaminid; 4. alabaminid-uvigerinid; 5. cribrostomoidosid-giroidinoid; 6. alabiminoidid-alabaminoid

VII. Astrorhizid-ammodiscid taxocoenosis.

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3. The Amphistiginid-planogipsinid genocoenosis is distributed through the southern subtropics at depths less than 100 m, in water temperatures of 20° to 25°C and dissolved oxygen content of 5 ml/l. Shells of genus *Amphistegina* comprise 45% and shells of genus *Planogypsina* comprise 41% of this genocoenosis.

4. The Cibicidesid-amphisteginid genocoenosis was found in the southern subtropics at 100 to 300-m depths and in water temperatures of 13° to 20°C, and in the tropics at 100 to 500-m depths, water temperatures of 10° to 25°C, and oxygen content of about 3 to 4.5 ml/l. In this genocoenosis, shells of genus *Cibicides* comprise 26%, and shells of genus *Amphistegina* - 25%. Genus *Siphonina* shells are about 15%. In the regions of deep cold water upwelling, this genocoenosis is replaced by the brizalinid-horkizinid genocoenosis (see below).

5. The Amphisteginid genocoenosis occurs in the tropics at depths less than 1,000 m and in water temperatures of 4° to 10°C. In this genocoenosis genus *Amphistegina* shells comprise 30 to 35%, while shells of agglutinating foraminifera comprise 10 to 15%.

6. *The Heterolepid genocoenosis* was found in the tropics near the coasts of the Philippines and New Guinea at 500 to 1,000-m depths and in water temperatures of 4° to 8°C. Genus *Heterolepa*
184 shells comprise 25 to 30% there. Shells of the remaining representatives occur in insignificant numbers of specimens.

At depths of 1,000 to 1,500 m, the amphisteginid genocoenosis is superseded in places by intermixed fauna. Shells of agglutinating foraminifera comprise approximately 25 to 30% in this fauna.

II. The Buliminid taxocoenosis is very widely distributed in the Pacific Ocean. In the boreal, northern subtropics, and Antarctic regions, it occupies the 0 to 200-m depth regions, while in the tropics, south subtropics, and notal region, it descends to 3,000-m depths. In the boreal, notal, and Antarctic regions, it ascends almost to 9 to 100 m. Compared with preceding taxocoenosis, this has colder water. Water temperatures of 2° to 10°C are typical. Shells of the order Buliminida usually comprise more than 50 to 60% in this taxocoenosis. Correlation between different genera of the order Buliminida varies within the taxocoenosis depending on latitude and depth and divides it into a series of genocoenoses. Their distribution depends mainly on water temperature and depth. Overall the Buliminid taxocoenosis contains 12 genocoenoses.

1. The Brizalid-Hopkinsinid genocoenosis occurs in the tropics at depths of 100 to 300 m. Its presence at small depths in the tropics is explained, it seems, by upwelling of cold water from great depths near the equator. In the Brizalinid-Hopkinsinid genocoenosis, the water temperature varies within 8° to 12°C limits. In this genocoenosis, shells of the genera Brizalina and Hopkinsina comprise approximately 30%, while 20% of the shells belong to the genus Cassidulina (fig. 70 does not show the location of this genocoenosis).

2. The Cassidulinid genocoenosis is at depths of 0 to 500 m in the boreal region, at 500 to 1,000 m in the northern and southern subtropics, and at 100 to 1,000 m in the notal region. In the region of this genocoenosis, water temperature varies within 2° to 7°C limits, while oxygen content ranges from 4 to 6 ml/l. Shells of genus Cassidulina comprise about 50% there. In the eastern part of the boreal region, near American shores, at 0 to 100-m depths, one finds a large number of representatives of the genus Textulariida whose shells comprise 25% in some areas. In the western part of the boreal region, near the coast of Kamchatka, at 300 to 500-m depths, large numbers of shells of the genera Recurvoides and Cribrostomoides (about 25%) occur.

In regions of low salinity (less than 32 ‰) water, the Cassidulinid genocoenosis usually is replaced by the Elphidiid genocoenosis at depths less than 300 m.

3. The Cassidulinid-Alabaminid genocoenosis was found only in the Antarctic region at depths of 100 to 1,000 m, in water temperatures of -1° to 11°C and oxygen contents of 4 to 6 ml/l. In this genocoenosis, Cassidulina shells comprise 25 to 35%, Alabamina shells - 15%. At 500 to 1,000-m depths, Alabamina shells comprise about 35%. In places in this genocoenosis, up to 10% of Quinqueloculina shells are found at depths less than 500 m.

4. The Bolivinid genocoenosis is distributed in the boreal region at depths of 500 to 1,500 m, in water temperatures of about 3°C and oxygen content of approximately 1 ml/l. Genus Bolivina shells comprise about 50% there. Among other species Cassidulina shells comprise up to 15 to 20% at depths less than 1,000 m. At 1,000 to 1,500-m depths, genus Bolivina shells comprise 15% in this genocoenosis, and genus Elphidium - 20%.

5. The Bolivinid-uvigerinid genocoenosis occurs in the boreal region at depths of 500 to 1,500 m, in water temperatures of
185 about 3°C, and oxygen content of about 1 ml/l. Genus Bolivina shells are about 50% here, and Uvigerina shells - approximately 40%.

185 6. The Bolivinid-globobuliminid genocoenosis was found in the Antarctic at depths of 1,500 to 2,000 m, water temperatures of about 1°C, and oxygen content of 4 to 4.5 ml/l. In this genocoenosis, genus Bolivina shells comprise approximately 50%, and Globobulimina - about 25%.

7. The Uvigerina genocoenosis occurs in the boreal region and northern subtropics at 1,500 to 2,000-m depths, water temperatures of approximately 3°C, and oxygen content of 1.5 ml/l in the boreal region to 2 ml/l in the northern subtropics. Shells of genus Uvigerina comprise about 30% here. In this genocoenosis, genus Elphidium shells in the boreal region comprise about 20%, while in the northern tropics, Cassidulina comprise 20% and genus Oridorsalis shells - 15%.

8. The Cassidulinid-Uvigerinid genocoenosis occurred in the tropics at depths of 1,500 to 2,000 m, water temperatures of 3° to 4°C, and oxygen content of approximately 2.5 to 3 ml/l. This genocoenosis is typified by a considerable diversity of predominant genera. Cassidulina shells comprise 32%, Uvigerina - 12%, Osangularia - 10%, and agglutinating foraminifera about 25%. The high content of the latter can be explained, perhaps, by cold water upwelling in this faunal region.

9. The Cassidellid-Buliminid genocoenosis was found in the tropics at depths of 2,000 to 2,500 m, water temperature of 2°C, and oxygen content of about 3 ml/l. In this genocoenosis, shells of genus Cassidella comprise 25%, Bulimina - 15.5%, and Alabamina - 10%. In regions of upwelling cold water, this genocoenosis is replaced by the Melonid-Laticarinnid.

10. The Cassidellid genocoenosis occurs in tropics at 2,500 to 3,000-m depths and a water temperature of about 2°C. About 70% of the shells there are genus Bulimina.

11. The Buliminid genocoenosis is distributed in the southern subtropics at 2,000 to 2,500-m depths, water temperature of approximately 2°C, and oxygen content of about 3.5 ml/l. About 62.5% of the shells in this genocoenosis are Bulimina and genus Cibicides comprise 15%.

12. The Ehrenberginid-Cassidulinid genocoenosis was found in the notal region at depths of 2,500 to 3,000 m, water temperature of about 2°C, and oxygen content of approximately 3.5 ml/l. In this genocoenosis, shells of genus Ehrenbergina comprise 26%, Cassidulina - 20%, and Heterolepa - 12%.

III. The Rotaliid -Buliminid taxocoenosis occurs in the southern subtropics and notal region at 1,000 to 2,000-m depths. Its presence in these regions is related, it seems, to the penetration of water from the Indian Ocean. This taxocoenosis consists of 3 genocoenosis.

1. The Buliminid-Nonionid genocoenosis was found in the southern subtropics at depths of 1,000 to 1,500 m, water temperatures of 3° to 5°C, and oxygen content of 3.5 ml/l. In this genocoenosis, shells of genus *Bulimina* comprise 15%, *Pullenia* - 12%, and *Melonis* - 10%.

2. The Buliminid-Oridorsalid genocoenosis occurs in the southern subtropics at 1,500 to 2,000-m depths, water temperatures of 2° to 3°C, and oxygen content of about 3.5 ml/l. In this genocoenosis, genus *Bulimina* shells comprise 33% and *Oridorsalis* - 27%.

3. The Heterolepid-Cassidulinid genocoenosis occurs in the notal region at depths of 1,000 to 1,500 m, water temperatures of 3° to 5°C, and oxygen content of about 4 ml/l. In this genocoenosis, shells of genus *Heterolepa* comprise 27%, *Casidulina* - about 20%. Agglutinating shells consisting of representatives of the genera *Karreriella* and *Cribrogoesella* comprise about 15%.

IV. The Trachomminid genocoenosis is distributed in the Antarctic
186 region at 1,000 to 1,500-m depths, water temperature of about 1°C, and oxygen content of about 4.5 ml/l.

V. The Cyclamminid-Cassidulinid genocoenosis was found in the Antarctic region at 2,000 to 2,500-m depths, water temperature of approximately 1°C, and oxygen content of about 4 to 4.5 ml/l. In this genocoenosis, shells genus *Cyclammina* comprise 35% and *Cassidulina* - about 17% of the shells in this genocoenosis. Representatives of the genera *Cribrostomoides* and *Saccorhiza* occur in relatively large quantities here.

VI. The Alabaminid taxocoenosis is very widely distributed in the Pacific Ocean: from the Aleutian chain to the Antarctic. In the boreal region, it occupies depths of 2,000 to 3,500 m, in the northern subtropics - 2,000 to 4,000-m depths. In the tropics, southern subtropics, and notal region, it occurred at depths of 3,000 to 4,500 m, and in the Antarctic - at 2,500 to 3,500 m. Shells of the Alabaminidae family comprise more than 50 to 60% in this taxocoenosis. This is the deepest water taxocoenosis of all the secretionary calcareous taxocoenoses in the Pacific Ocean. Water temperatures of about 2°C are typical of this taxocoenosis. It is very monotypical in its species and genera composition compared with the Buliminid taxocoenosis. It has only 7 genocoenoses.

1. The Oridorsalid-Eggelerid genocoenosis was found in the boreal region at depths of 2,000 to 2,500 m, water temperatures of about 2°C, and oxygen content of 2 ml/l. In this genocoenosis, shells of genus *Oridorsalis* are about 35% and *Eggerella* about 25%.

2. The Oridorsalid-Ehrenberginid genocoenosis is distributed in the northern subtropics at 2,000 to 2,500-m depths, in water

temperatures of about 2°C, and oxygen content of 2.5 ml/l. Twenty-seven percent of the shells in the genocoenosis are genera *Oridorsalis* and *Ehrenbergina*.

3. The Oridorsalid-Alabaminid genocoenosis occurs in the northern subtropics at 2,000 to 2,500-m depths, water temperatures of about 2°C and oxygen content of 1.5 ml/l. In this genocoenosis, shells of genus *Oridorsalis* comprise about 30%, *Alabamina* - 25%, and Heterolepa - 7%.

4. The Alabaminoidid-Uvigerinid genocoenosis occurs in the northern subtropics and Antarctic at depths of 2,500 to 3,000 m, water temperature of approximately 1° to 2°C, and oxygen content of about 2.5 to 4.5 ml/l. In this genocoenosis, genus *Pseudoalabamina* shells comprise 42% in the northern subtropics and 33% in the Antarctic. Genus *Uvigerina* shells comprise 20% in the Antarctic and 15% in the northern subtropics. A large quantity of genus *Cassidulina* shells (10%) also occur in this genocoenosis in the Antarctic.

5. The Cribrostomoidid-Gyroidinid genocoenosis is distributed through the boreal region at depths of 3,000 to 3,500 m, in water temperature of 1° to 2°C and oxygen content of about 2.5 ml/l. The name of this genocoenosis was assigned somewhat conditionally. It is well intermixed. Secretionary foraminifera comprise 58% of it. Among these foraminifera, genus *Gyroidina* shells are encountered in greater quantities (10%). Agglutinating foraminifera comprise 42% and are mainly of the genus Cribrostomoides (22% of the shells there).

6. The Alabaminoidid-Alabaminid genocoenosis is very widely distributed at depths greater than 3,000 m. In the northern subtropics, it descends to 4,000 m, in the tropics, southern subtropics, and notal region - to 4,500 m, and in the Antarctic region - to 3,500 m in waters with temperatures of about 1° to 2°C, and oxygen content from 3 ml/l in the north to 4.5 ml/l in the south. Shells of *Alabaminoides* and *Alabammina* genera comprise the greatest percentage in this genocoenosis. These two genera replace each other from north
187 to south. In this genocoenosis, genus *Alabamminoides* shells predominate north of the notal region, comprising 50 to 60% there. In the notal and Antarctic regions genus *Alabamina* shells comprise 40 50%, Alabaminoides shells - 20 to 30%.

VII. The Astrorhizid-Ammodiscid taxocoenosis is the deepest-water one of all benthic foraminiferal taxocoenoses. It occupies the entire abyssal zone of the Pacific Ocean (depths greater than 3,500 to 4,500 m) and descends to maximum depths. The leading genera of this taxocoenosis are as follows: *Rhabdammina*, *Bathysiphon*, *Dendrophrya*, *Normanina*, *Pseudonodosinella*, *Cribrostomoides*, and *Nodosinum*. Large shells and relatively primitive genera are characteristic of this taxocoenosis. Habitat conditions required for this

taxocoenosis are as follows: great depths, constant low water temperatures (below 1° to 2.0°C), high water density (above 27.7), and lack of competing secretionary foraminiferal fauna. This taxocoenosis is represented by approximately the same genera in abyssal depths throughout the Pacific Ocean.

FACTORS THAT DETERMINE THE DISTRIBUTION OF BENTHIC FORAMINIFERA

Study of the distribution of benthic foraminifera in the Pacific Ocean has shown that this distribution depends on two types of zoning, latitudinal and bathymetric.

The latitudinal (or climatic) zoning of foraminifera depends mainly on water temperature and salinity, i.e. factors which at the same depths and constant pressure are determined by the density of water. The latter influences the gas regime which plays a decisive role in the distribution of benthic foraminifera, because solubility of salts which form part of their shells depends on this regime. Bathymetric (or barometric) zoning is manifested through pressure and water temperature, which determine vertical water density and, consequently, determine the gas regime. Combination of these main types of zoning creates diversity of ecological niches (and, consequently, also diversity in the distribution of benthic foraminifera), as is observed in the Pacific Ocean.

Bathymetric zoning of foraminifera is revealed quite clearly in vertical replacement of benthic foraminiferal species and appears quite evenly in all latitudes. This zoning is shown in terms of quantitative distribution through alternation of minima and maxima foraminiferal shell content. Benthic secretionary foraminifera were found above 3,500 m depths in boreal and Antarctic regions and above 4,500 m in tropical and notal regions. In boreal and Antarctic regions, these foraminifera form three maxima: on the shelf, on the upper slopes, and on the lower slopes. The fourth maximum of these foraminifera is the deepest one and appears only at 2,750-3,250 to 4,500-m depths in tropical and notal regions. Agglutinating foraminifera form 5 maxima in the Pacific Ocean. Four of these were encountered in the entire ocean. These are the maxima found on the shelf, lower and upper slopes, and on the ocean floor. The fifth maximum is the deepest one and occurs only in abyssal troughs. All quantitative maxima of benthic foraminifera shift slightly upward in transition from boreal into notal regions.

Study of vertical distribution of individual species has shown that the continental shelf, slope, and ocean bed differ in foraminiferal species composition and have very few species in common.
188 Species found in two adjacent geomorphological zones, produce a quantitative maximum in only one of those zones.

In boreal and Antarctic regions, vertical variation of numbers and types of foraminifera is determined mainly by pressure, which varies from 1 atmosphere, at the water surface, to 1,000 atmospheres at 10,000-m depth. In these latitudes, a decisive role also is played by the content of dissolved oxygen in water, which increases from 1 to 7 ml/l as depth decreases. It seems that water temperature plays a lesser role in these regions, especially in the polar region where the variation of temperature with depth is insignificant and lies within 1° to 2°C limits. In the tropics, the decisive role is played by water pressure, and temperature which changes with depth from 1.5° to 25°C. The dissolved oxygen content varies little vertically (from 1.5 to 3.5 ml/l) in the tropical waters and seems to exert little influence on the distribution of foraminifera.

Latitudinal zoning, as well as hypsometric, is reflected in replacement of species and in the quantitative composition of benthic foraminifera. The population density of secretionary foraminifera varies greatly with latitude mainly above 500-m depths, while agglutinating foraminifera vary greatly below 3,000 m. For example, in the tropics, the quantity of secretionary foraminifera quadruples, while at 1,000 to 3,000-m depths it increases only one and a half times compared with the boreal region. Above 500-m depths, specimens of agglutinating species are most numerous in the Antarctic and tropical regions, where their quantity is two and a half times greater than in other regions. At depths of 1,000 to 3,000 m the quantity of these foraminifera varies very little, while below 3,000-m depths, they double in the boreal and notal regions compared to tropics.

The most abrupt replacement of foraminiferal species composition occurs in the transition from the tropical to boreal regions, approximately in the 30° to 40° (of latitude) region, and from notal to the Antarctic regions, between 60° to 70°. The number of latitudinally endemic species of benthic foraminifera increases inversely with depth, and reaches a maximum above 400 m.

Latitudinal variation of the distribution of foraminifera at depths less than 200 to 500 m relates principally to variations of water temperature and salinity. At these depths, the horizontal temperature gradient increases in transition from high to low latitudes, from 1 to 25°C while salinity increases from 33.0 to 35.7‰. At depths of 1,000 to 2,000-2,500 m, horizontal temperature and salinity gradients change very slightly latitudinally, temperature varies up to 1°C, salinity up to 0.1‰. Consequently, it seems that the horizontal distribution of foraminifera at these depths is influenced first of all by the dissolved oxygen content, which changes from north to south from 1.0 to 4.5 ml/l, and, to a lesser degree, by salinity and temperature. At depths greater than 2,000 to 2,500 m, the latitudinal distribution of bottom foraminifera depends mainly on the oxygen content and saturation of the water with $CaCO_3$.

The data presented on the distribution of foraminifera confirms conclusions by Mayers (1957) based on generalization from data on foraminiferal ecology. He concluded that the distribution of foraminifera is influenced by a series of factors, among which the factor with sharp fluctuation limits has the greatest influence.

The food factor also has an unimportant significance. It is especially clearly shown and is a leading element in the distribution of abyssal agglutinating foraminifera on the surface of the bottom, forming a quantitative maximum on the ocean floor at depths of 3,000
189 to 6,500 m. As can be seen from charts of the distribution of these foraminifera in the abyssal zone of the Pacific Ocean, they are unevenly distributed in spite of the existence of suitable depths. In the boreal and notal zones, they are numerous almost everywhere. In these regions, plankton biomass is maximum, according to Vinogradov's (1960) data, and plankton detritus is the main food source of foraminifera there. In tropical ocean regions, agglutinating foraminifera of the ocean bottom occur in minimum quantities only in regions adjacent to dry land or bottom elevations. It seems that the low plankton biomass in the tropics does not provide enough nutrient substances to the bottom, and the area of maximum quantitative numbers of ocean bottom foraminifera shrinks to the shallower water, elevated regions - seamounts, ridges, and elevations, over which plankton biomass probably is considerably larger and creates an adequate food base. Increase of plankton biomass near underwater ridges was noted by V. G. Bogorov and M. E. Vinogradov (1961) in the Indian Ocean.

It seems that all foraminifera at relatively shallow depths (less than 3,500 m) feed not only on plankton detritus, but also on the remains of bottom organisms, whose biomass increases considerably at these depths (Zenkevich, Filatova, 1957; Zenkevich, Barsanova, Belyayev, 1960). As mentioned by many authors (Mayers, 1943; Lalicker, 1948; Zalesky, 1959), when the food supply is inadequate, foraminifera develop small, smooth, and weakly sculptured, assymmetric shells with wider inlet surfaces.

Comparing charts of contemporary quantitative distribution of foraminifera with bottom relief charts, the dependence of foraminiferal distribution on bottom relief is obvious. The number of foraminiferal specimens in bottom depressions at any given depth is always relatively smaller than on elevated relief features.

For example, in the Sea of Okhotsk, the fewest bottom foraminifera typically occur in TINRO, Deryugin, and Southern Abyssal troughs and in the deepest sectors of the northern Continental Shelf, while they are most numerous in the coastal zone and on Shirshov submarine ridge.

In the Pacific Ocean zones where benthic foraminifera are most numerous they are confined to elevated sectors of the continental shelf

and slope, and, in the open ocean, to Cocos, Nasca, Sala-y-Gomez, and Lord Howe ridges, Emperor and Markus-Necker seamounts, Albatross, East Pacific, and South Pacific rises, and the submarine slopes of island arcs and massifs. The fewest benthic foraminifera are confined to the Northwest, Northeast, Central, Southern, Bellingshausen, Chile, Peru, and Guatemala basins, as well as to the basins of marginal seas and abyssal trenches. Consequently, based on charts showing quantitative distribution of any foraminifera in the past, one can infer the main bottom relief aspects of that time, and using bottom relief as a basis, can infer the quantitative foraminiferal distribution pattern.

In the future, all these facts will make it possible, from charts of the quantitative distribution of foraminifera of an ancient horizon, to infer the bottom paleorelief in existence during deposition of sediments of that horizon, while based on bottom relief one will be able to infer the quantitative foraminiferal distribution pattern.

190 Currents significantly influence the distribution of benthic foraminifera only in relatively shallow depths (less than 1,000 m), extending from one latitude region into another. In the Pacific basin, these conditions are met by the coast of North America from 30° to 50°N and the coast of South America from 20° to 40°C. Otherwise, currents alter the general zone pattern of foraminiferal distribution either very little or not at all. Sediment composition undoubtedly has great influence on the distribution of benthic foraminifera, because sediments are their substrata, but determination of the pattern foraminiferal distribution from sediment type is made difficult because during analysis of the sediments, benthic foraminifera are not excluded from these sediments and influence the granulometric and mass-genetic composition of the sediments.

At the present time, it should be noted, that shallow-water foraminifera prefer to live on sediments coarser than those favored by the deep-water species. In regions of fine ooze on the continental shelf, sublittoral foraminifera usually are fewer in numbers, while deep-water species are most numerous in fine oozes.

As substrata eaters, agglutinating foraminifera prefer to live in fine sediments with a high content of iron oxides, which form a part of their shell cement. As filtering organisms, secretionary foraminifera live mainly on sediments that are coarser than those of agglutinating foraminifera, and they prefer carbonate substrata where the water is saturated with carbonates needed to construct their shells.

DISPLACED BENTHIC FORAMINIFERA

Shells of species that are not a part of the foraminiferal complex of the area where the bottom sample was taken were found, during study of contemporary bottom foraminifera, in some bottom sediment samples. For example, poorly preserved shells of species that live at depths less than 200 to 300 m were found at depths greater than 3,000 m north of 40°N and west of 170°W in the North Pacific Ocean. The poor state of preservation of the shells (usually they are chipped) and their presence far from the coast can be explained only by ice rafting. Such foramifera have been found on several stations: 2121, 2154, 3246, 3325, 3357, 4068. Individual specimens of *Elphidium subclavatum* and *Cassidulina californica*, which are most widely distributed on the Aleutian Chain shoals, were found at these stations.

Shells of foraminifera that now live mainly on the continental shelf, but are not members of the species complex or depths of the place where they were encountered, were found at depths greater than 3,000 m at the remaining stations.

All stations where the above phenomena were found can be divided into two groups. Stations 2208, 2217, 3145, 3338, 3363, 3402, 3471, 3495, 3500, 3503, 3625, 3663, 3668, 3725, 3752, 3793, 3805, 3818, 3871, 3984, 3997, 4004, 4074, 4087, 4112, 4124, 4187, 4209, 4289, 4311, 4325, 4335, 4343, 4347, 4355, 5062, 5110, 5124, and stations 402 and 444 of the OB' belong to the first group. At these stations, shells of foraminifera not belonging to the local species complex occurred as small (less than 0.1 mm) individual specimens, which frequently had a rounded off appearance or were chipped. There are usually no more than 2 to 3 such misplaced species. Their presence cannot be fully explained by ice rafting, even in the northern part of the Pacific Ocean, because they live at such depths that water does not freeze, especially in the tropics. It is possible that their
191 appearance at the unusual depths is related to turbidity current action.

Stations 3509, 3535, 3684, 3825, 3868, 4131, 4156, 4191, 4225, 4239, 4253, 5071, 5074, 5080, 5082, 5113, 5126, 5136, 5139 and stations 361, 363, 365, 381, 396, 413 of the OB' belong to the second group. At these stations, foraminifera not belonging to the local species comples and depths usually are represented by a large number of species and specimens. The degree of preservation of the shells does not differ from that of shells of the local complex. The shells are of different size - from largest to smallest.

In actual fact, on these stations one usually observes an intermixture of two adjacent foraminiferal complexes, based on habitat conditions. The study of foraminiferal distribution in Pacific Ocean core samples has shown that these complexes eventually replace each other. There are no indications that they were carried to the sites

mentioned. However, the slowest sedimentation rates and the thinnest contemporary sediments (the uppermost stratigraphic horizon), which usually are less than 2 to 3 cm and in places are 4 to 5 cm, are typical of the regions where the stations are located. The surface samples, especially those of dredge samplers, taken at these stations usually are thicker than the contemporary sediment layer. Consequently, one can infer, that contemporary sediments were intermixed with sediments of the underlying layer, and this led to intermixing of the foraminiferal complexes.

In order to avoid such occurrences in the future, the topmost layer should be removed from contemporary sediment samples before they are taken from the sampler.

In trawl samples from regions where the contemporary sediment thickness is less than 15 to 20 cm, intermixed faunas of bottom foraminiferal faunas also usually are found. Very frequently the trawl scrapes off not just the contemporary sediments, but also Late Quaternary and Tertiary sediments, especially from the slopes of abyssal trenches. The sediments are washed as the trawl is raised, and the foraminifera are washed out, from the intermixed contemporary and ancient deposits. On steep slopes, where sediment slumping frequently occurs, the trawl may bring up only the ancient foraminiferal fauna.

CONCLUSIONS

1. Benthic foraminifera are distributed everywhere in the Pacific Ocean. The greatest number of species occurred in the tropics, while the fewest were found in the boreal and Antarctic regions. Agglutinating foraminifera are represented by similar numbers of species at different depths. Secretionary foraminifera, which are "filtering" organisms, were found only at depths less than 3,500 to 4,500 m. The number of their species increases inversely with depth and reaches a maximum at depths less than 500 m.

Agglutinating foraminifera, which feed mainly on the substrata, are most widely distributed in regions of high plankton biomass in the boreal, notal, and Antarctic regions at depths greater than 3,000 to 4,000 m where non-carbonate sediments are developed.

The following generalizations typify all orders and genera of benthic foraminifera: decrease in the number of species at depths greater than optimum and at temperatures below optimum; the number of species which adapt to low temperatures is usually high; decrease in the population density at depths smaller than optimum and at temperatures higher than optimum; the number of species can remain the same.

192 Agglutinating foraminifera of the Pacific Ocean belong to 4 orders. Water temperatures below 3°C are most favorable for the orders Astrorhizida and Ammodiscida. They develop the largest number of species and densest populations at these temperatures and at shallow and great depths. Water temperatures above 15°C and depths less than 500 m and 1,000 m are optimum for the orders Textulariida and Ataxophragmiida. The family Trochaminidae, belonging to Ataxophragmiida, is an exception. Depths greater than 2,000 m and water temperatures below 2° to 3°C are most favorable for it.

Secretionary foraminifera consist of 6 orders. Depths less than 400 m and water temperatures of 15° to 20°C are optimum for the order Miliolida. Depths of 300 to 500 m and water temperatures of 8° to 15°C are optimum for the order Lagenida. Depths less than 1,000 m and water temperatures above 15°C are optimum for most representatives of the order Rotaliida although it seems to be a composite order. The warmest-water order is Nummulitida and water temperatures above 20°C and depths less than 300 m are optimum for it. It is difficult to determine optimum conditions for the order Buliminida as a whole. Its representatives are more cold resistant than other orders. Water temperatures above 10°C and depths less than 400 m are favorable for species of the Bolivinidae family, which belongs to the order Buliminidae.

2. Based on quantitative and qualitative analysis of foraminifera and statistical processing of these analyses, different benthic foraminiferal faunas and taxocoenoses can be distinguished in the Pacific Ocean. Percentage correlation of the number of species of various orders has revealed two principal oceanic faunas. The first, sublittoral and bathyal zone fauna, is distributed at depths less than 3,000 to 4,500 m and consists of up to 50 to 60% secretionary species. This fauna consists of cold-water, temperate, and warm-water forms. The second, abyssal zone fauna, is distributed at depths greater than 3,000 to 4,500 m and consists of up to almost 100° of agglutinating foraminifera. Overall, this is a cold-water fauna. The percentage correlation of shells of various foraminiferal orders reveals the presence of four taxocoenoses of oceanic type in the Pacific Ocean: asterigerhinid, buliminid, alabaminid, and astrorhizid -ammodiscid.

The Asterigerinid taxocoenosis occupies the tropical region and descends to 500-m depths in the subtropics and to 1,000 m in the tropics. Typical water temperatures for this taxocoenosis are 10° to 25°C.

The Buliminid taxocoenosis occurs in the boreal and Antarctic regions down to 2,000-m depths. In the northern subtropics it was found at depths of 500 to 2,000 m, in the tropics at 1,500 to 2,000 m, in the southern subtropics at 500 to 3,000 m, and in the notal region at 0 to 3,000 m. This is more of a cold-water texocoenosis than the

preceding one. Overall, water temperatures of 2° to 10°C are favorable to it.

The Alabaminid taxocoenosis is located deeper than the Buliminid. In the boreal and Antarctic regions, it descends to 3,500-m depths, in northern subtropics to 4,000 m, and in the other regions to 4,500 m. This is a colder water taxocoenosis than the preceding one. It favors water temperatures of about 2°C.

The Astrorhizida-Ammodiscida taxocoenosis occupies the deepest regions of the ocean and is deeper than the Alabaminida. Water temperatures in its region are below 2°C.

The Asterigerinid and Buliminid taxocoenoses consist of species that, in most cases have calcite shells with a crypto crystalline radiating wall structure. They predominate at depths of up to 2,000 to 3,000 m.

193 The Alabaminid taxocoenosis is represented by species that have calcite shells with granular or microcrystalline radiating wall structure and occupy 2,000-3,000 to 3,500-4,500 m depths.

The Astrorhizid-Ammodiscid taxocoenosis consists of species with agglutinating arenaceous shells, whose cement is microgranular and calcareous. This taxocoenosis occurs at depths greater than 3,500 to 4,500 m.

Such distribution by depth of foraminiferal coenoses, consisting of species of varying composition and shell structure, depends on the pressure, which depends on depth in the ocean (figs. 66 & 67).

Oceanic taxocoenoses consist of genocoenoses with narrower distribution ranges. Latitudinal and vertical replacement of the genocoenoses within the oceanic ones depends on different factors: depth, temperature, salinity, oxygen content of water, etc. In each specific case the most significant factor is the one that varies the most. At the present time, 29 genocoenoses have been identified in the Pacific Ocean.

One should note especially, that individual specimens of two secretionary species of the order Miliolida, which were shown by chemical analysis to contain twice as much magnesium than those of shallow-water Miliolida, were found in the boreal region at great depths down to 6,000 m. Their wall structure is still unknown. It seems that they cannot be classified as typical calcareous foraminifera, but probably belong to the magnesium-calcareous type. Large miliolids, whose shells are covered by a thin homogeneous layer of silicon, and small miliolids, whose shells consist of chemogenic silica, were found at 7,230-m depths.

3. Throughout the Pacific Ocean, benthic foraminiferal species appear to be stenobiontic. Each species lives within strictly defined, very specific conditions of depth, salinity, water temperature, oxygen content, etc. A specific complex of these conditions, forms and delineates the distribution range of each species. The smallest changes in conditions appear as unsurmountable barriers to the distribution of individual species. Consequently, distribution ranges of species are very limited vertically, as well as horizontally. Undoubtedly, this specific phenomenon explains the presence of considerable numbers of benthic foraminiferal species in the Pacific Ocean. It is also possible that identification of "cosmopolitan" species of foraminifera is a result of insufficient study.

Ranges of genera of taxocoenoses can be subdivided into two groups. The first group consists of obviously stenobiontic genera, while the second - of relatively eurybiontic (genera). Through formal investigation, the ranges of genera of the second group can appear to be very extensive. However, detailed study shows that in spite of their large horizontal and vertical extent they are also limited. Salinity is a barrier for some species, temperature for others, and oxygen content of water for a third group.

4. Study of Pacific Ocean foraminifera has shown that their distribution depends primarily on two types of zoning: latitudinal and bathymetric. These zones are seen in the distribution of benthic foraminifera and in replacement of species and larger systematic groups.

These two types of zoning are superimposed on other factors not subject to zonal distribution; these are mainly bottom relief (submarine ridges, rises, depressions, etc) and east-west currents.

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